SANTA ANA RIVER HYDROELECTRIC SYSTEM
SAN BERNARDINO NATIONAL FOREST
REDLANDS VICINITY
SAN BERNARDINO COUNTY
CALIFORNIA

HAER No. CA-130

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PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENIGNEERING RECORD
NATIONAL PARK SERVICE
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DEPARTMENT OF THE INTERIOR
SAN FRANCISCO, CALIFORNIA 94107

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HISTORIC AMERICAN ENGINEERING RECORD

SANTA ANA RIVER HYDROELECTRIC SYSTEM

HAER No. CA-130

Location:	The southern boundary of the Santa Ana Hydroelectric System is located in the Santa Ana River Canyon, 1.4 miles northeast of the City of Redlands in San Bernardino County, California and 0.52 mile northeast of Greenspot Road. The distance between the northern and southern ends of the system is approximately 3.8 miles, oriented southwest to northeast. USGS Yucaipa and Keller Peak Quadrangles, Universal Transverse Mercator Coordinates: North end (SAR 1): 10.494720.3778100. South end (SAR 3):10.490900.3773920
Date of Construction:	SAR 1 - 1898; SAR 2 - 1905; SAR 3 - 1904
Engineer:	O. H. Ensign; E. M. Boggs
Builder:	Thornton and Leonardy, Redlands; Mentone Power Company (SAR 3)
Present Owner:	Southern California Edison Company, P.O. Box 800, Rosemead, California 91770
Present Use:	Operating hydroelectric generating facilities to be affected by new Seven Oaks Dam
Significance:	When completed in 1898, Powerhouse 1 had the longest transmission line in the country, and possibly the largest hydroelectric generators in the world. Innovative features which became industry standards include the individual tail races, internal revolving field alternators, and transposition of wires. When Powerhouses 2 and 3 were added, the system became tbe prototype for the larger hydroelectric systems of the twentieth century. Nominated to the National Register of Historic Places in 1985; American Society of Civil Engineers Historic and Engineering Landmark in 1985.
Report Prepared by:	Mark T. Swanson, Historian Greenwood and Associates 725 Jacon Way Pacific Palisades, California 90272-2830 David De Vries, Photographer Mesa Technical 2630 Hilgard Berkeley, California 94709-1002
Date:	November 1992

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SANTA ANA RIVER HYDROELECTRIC SYSTEM

1. INTRODUCTION

Environmental Setting

Santa Ana River Powerhouses 1, 2, and 3, collectively known as the Santa Ana River Hydroelectric System, are located along the Santa Ana River, between the higher elevations of the San Bernardino Mountains and the mouth of the Santa Ana Canyon at Mentone. The three Santa Ana River powerhouses, and their water intake systems, are all linked together, making use of the same water at successively lower elevations along the Santa Ana River. The whole system is located in the mountainous San Bernardino National Forest, San Bernardino County, California, about 70 miles due east of downtown Los Angeles (Figure 1).

The three facilities, currently known as Santa Ana River Powerhouses 1, 2, and 3, are often abbreviated to SAR 1, SAR 2, and SAR 3. Powerhouse 1 is the highest in elevation, followed by the other two in sequential order. The intake for Powerhouse 1 is located near the northeast corner of Section 19, Township 1 North, Range 1 West, San Bernardino Base Meridian. From there, the water conduit extends slightly more than 2.5 miles on the north and west side of the Santa Ana River to Powerhouse 1, located in the northeast quarter of Section 26, Township 1 North, Range 2 West. From the tailrace of SAR 1, the conduit of Powerhouse 2 crosses the river and extends just over 1.5 miles on the south and east side to Powerhouse 2, located in the northeast quarter of Section 34, Township 1 North, Range 2 West. From the tailrace of SAR 2, the conduit for Powerhouse 3 continues on the south and east side of the river for another 2.5 miles until it reaches Powerhouse 3, situated in the southwest quarter of Section 4, Township 1 South, Range 2 West (CA-130-56). The total distance covered by this system, from the intake of SAR 1 to the tailrace of SAR 3, is 7.06 miles (Hornbeck and Botts 1988:19).

There is a discrepancy among the most reliable sources as to the elevation of the system, especially SAR 1. To compound the problem, local USGS quadrangle maps vary yet again from the sources. The most accurate elevations appear to be those used by C.E. Fowler in an 1899 article describing the construction and operation of Santa Ana No. 1. The other disagreements are relatively minor. With these provisos, the total drop in elevation within this system, from the intake of Powerhouse 1 to Powerhouse 3, is roughly 1472 feet. The SAR 1 intake is located at approximately 3422 feet above mean sea level (AMSL). Water collected here drops 752 feet into Powerhouse 1, situated at 2670 feet AMSL (Fowler 1899:146). The water again drops another 320

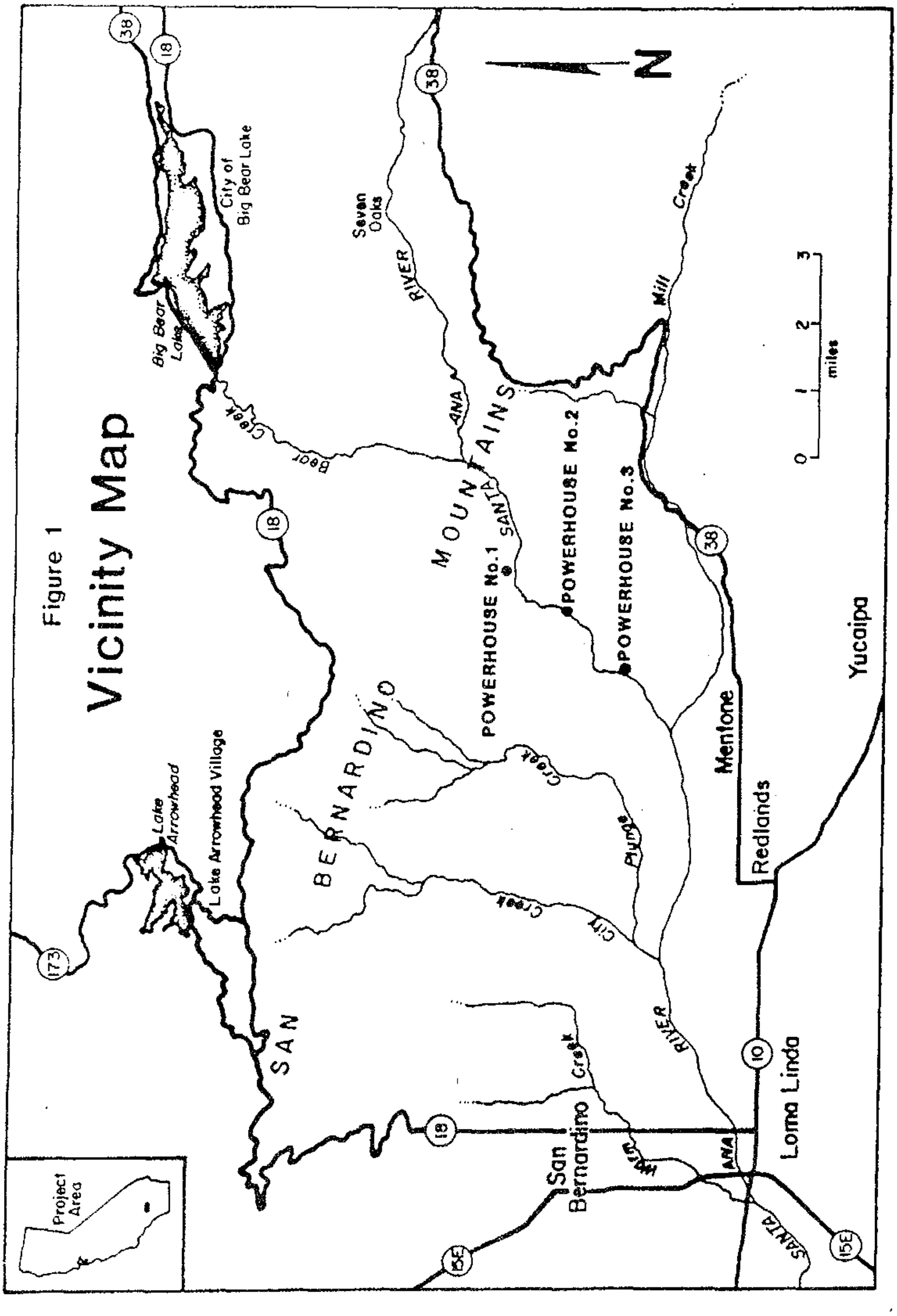


Figure 1
Vicinity Map
N
0 1 2 3
miles
Project Area
Big Bear Lake
City of Big Bear Lake
Seven Oaks
Lake Arrowhead
Lake Arrowhead Village
SAN BERNARDINO MOUNTAINS
SANTA ANA RIVER
POWERHOUSE No.1
POWERHOUSE No.2
POWERHOUSE No.3
Bear Creek
Mill Creek
Plunge Creek
City Creek
Creek
Mentone
Redlands
Yucaipa
Loma Linda
San Bernardino
38
18
173
10
15E

feet to Powerhouse 2, situated at 2350 feet AMSL. The final drop of 400 feet goes into Powerhouse 3, situated at 1950 feet AMSL (Hornbeck and Botts 1988:20-21).

The three powerhouses are located within the San Bernardino Mountains, one of the east-west Transverse Ranges of southern California. The Transverse Ranges create the mountainous northern rim of the Los Angeles Basin. Within these ranges, the San Bernardino Mountains form a relatively compact group, separated from the San Gabriel Mountains to the west by the Cajon Pass, and differentiated from the Little San Bernardino Mountains to the east by Morongo Valley (Sharp 1976:10-12). The San Bernardino Mountains are among the highest that form the Los Angeles Basin, and the streams that flow from these mountains are some of the largest in southern California.

The central portion of the San Bernardino Range is divided into three east-west trending valleys, all of which drain to the west or southwest (Figure 2). The northernmost of these valleys is Bear Valley, drained by Bear Creek. The central valley, also known as the Seven Oaks area, is formed by the upper reaches of the Santa Ana River. The southern valley is formed by Mill Creek. Bear Creek and the upper Santa Ana are separated by Sugarloaf Mountain (9952 feet AMSL) and its ridges. Bear Creek and the upper Santa Ana River join before they leave the mountains. Together they drain an area that encompasses some 166 square miles (Fowler 1923:587). Mill Creek, though immediately to the south, does not enter into this system. The upper Santa Ana and Mill Creek are separated by the massive San Gorgornio Peak and its outlying ridges. San Gorgornio, at 11,499 feet AMSL, is the highest point in southern California. The ridges west of San Gorgornio keep Mill Creek from flowing into the Santa Ana River until both are on the floor of the San Bernardino Valley.

Due to fault action, the San Bernardino Mountains are still rising. They are also subjected to fierce water erosion. For this reason, rivers and creeks in the San Bernardinos are deeply incised, creating steep-walled canyons. To compound this problem, most of the San Bernardino Mountains consist of badly decomposed granitic rock, unlike the San Gabriels which are characterized by a better quality of granite. In times of heavy seasonal rains, flood waters in the San Bernardino Mountains will dislodge boulders and move enormous quantities of sand (Fowler 1923:590; Keep, personal communication 1992).

Rainfall in southern California is highly seasonal, with relatively heavy winter rains and drought conditions in summer. Since winter storms come in from the Pacific and back up against the mountains, the western and southern slopes of the Transverse Ranges receive the most precipitation (Fowler 1923:Plate II,21). In fact, the area around San Gorgornio Peak receives the highest average precipitation of any other area in southern California,

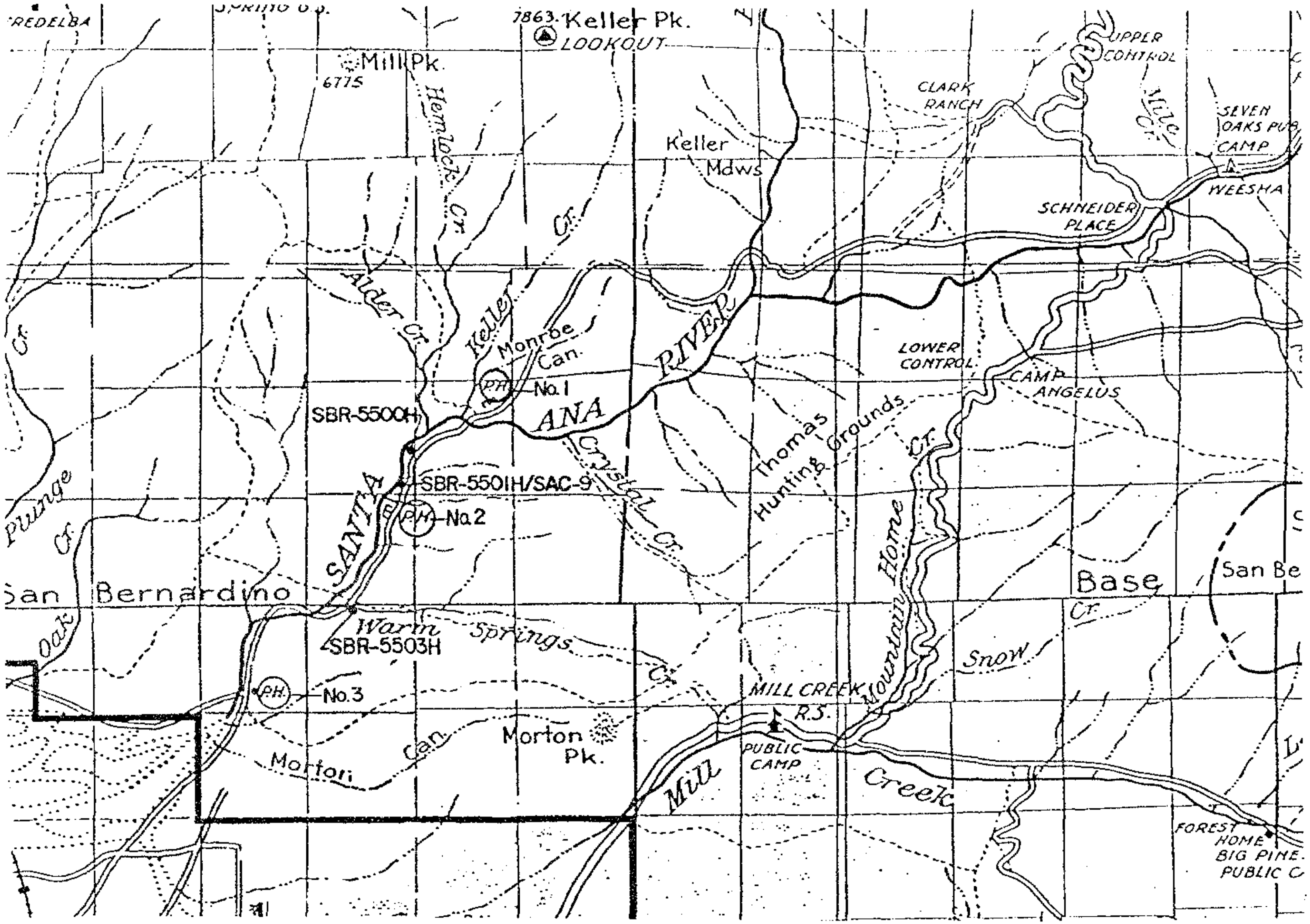


Figure 2. Drainage Basins and the Powerhouses (Anon. map, ca. 1930)
(On file, Bear Valley Mutual Water Company, Redlands)

around 40 inches per year. Bear Valley, just 10 miles to the north, receives around 33 inches. Even this is considerably more than that received by the foothill area around the powerhouses, which gets about 15 inches per year (Fowler 1923:587). On the valley floor, the amount is even less, approximately 12 inches.

Not only do the mountains receive greater precipitation, but they tend to keep their winter moisture far longer than the valleys below. For one thing, the mountains themselves are natural shields against the summer sun. Since the valleys in the central San Bernardinos are east-west trending, there are large north slopes that support a far more luxurious growth of trees than do the south slopes just a few miles away.

There are additional factors that conspire to keep surface water limited to the mountains of southern California. The mountain elevations are cooler than the interior valleys, which keeps down the enormous evaporation rate that plagues the lower elevations in summer months. The mountain snow pack also provides water run-off well into spring and summer, extending the life of the wet season in the mountains. This is especially pronounced on the cooler north slopes of the San Bernardino Mountains. In fact, the only reason the upper Santa Ana River flows year-round is because it receives run-off from the massive north slope of San Gorgornio Peak.

Upper mountain streams also tend to flow perennially because their channels are rocky; ground seepage is a minimal problem. This is quite the reverse in the San Bernardino Valley, which was created by alluvial sands from the neighboring mountain streams. Between ground seepage and the high evaporation rate, the Santa Ana River rarely made it to the sea with a surface flow in early historic times. By the late 1800s, with the advent of agricultural pumping, the river usually disappeared on the floor of the San Bernardino Valley. By the late 1800s, it was clear that only the mountains had the two absolute prerequisites for the development of hydroelectric power in southern California: elevation and a steady supply of water.

Historical Setting

As the population of the Los Angeles Basin grew, it was to the mountains around the basin that people turned for irrigation water and, finally, hydroelectric power. In addition to the development of irrigation canals, all three valleys of the San Bernardino Range were tapped for hydroelectric power. Mill Creek was put to work as early as 1893. The Santa Ana River and Bear Creek were exploited by the Santa Ana River hydroelectric system, which began with SAR 1 in the late 1890s and was completed by SAR 2 and SAR 3 in the early 1900s.

At present, all three Santa Ana River powerhouses are owned and operated by Southern California Edison Company, but this was not the case at the time of their construction. Powerhouse 1 is the oldest of the three, constructed in 1897-1898. The Southern California Power Company did most of the construction work before the facility was bought outright by Edison's principal predecessor, the Edison Electric Company of Los Angeles. SAR 1 was put into operation in early 1899. Powerhouse 2 was begun by Mountain Power Company, a subsidiary of Edison Electric, as early as 1900, but work did not begin in earnest until after 1902, when the project was absorbed directly into the Edison system; Powerhouse 2 was completed in 1905. Powerhouse 3 was constructed by the Mentone Power Company in 1904 and was not absorbed into the Edison system until 1917. For this reason, Powerhouse 3 is even today sometimes known as the "Mentone Plant." The history of these powerhouses and their importance to the technological development of southern California -- and the history of electricity itself -- are the themes examined in this study.

The Santa Ana River Hydro System, which stretches from the intake of Powerhouse 1 to the tailrace of Powerhouse 3, is still considered today an efficient means of electrical generation. When the system was inaugurated around the turn of the century, it was nothing less than a technological wonder. There are several reasons why the Santa Ana River Hydro System and its components occupy an important place in the technological development of southern California. Powerhouse 1, at the time of its construction, was the largest high-head hydroelectric plant in the United States, and was the first in this country to transmit high voltage commercially over long distances. The transmission line, stretching from SAR 1 to the west side of Los Angeles, was 82 or 83 miles, considered to be the longest commercial line in the United States at the time. When the other two plants were completed, the Santa Ana system was one of the earliest examples of using the same water at successively lower elevations. Together with the Mill Creek powerhouses, located just four miles to the east, the system was a prototype for the efficient generation of hydroelectric power (Secord 1985).

Relatively few changes have occurred to the Santa Ana River system since the turn of the century, which is itself a unique feature. There have been modifications and upgrades to the intakes, flumes, electrical wiring, transformers, and transmission lines, but the powerhouses themselves are virtually in their original state. Most of the original generators are still in service (Secord 1985).

To place the development of the Santa Ana River Hydro system into its historical and technological context, it is necessary to provide information about a number of interrelated areas. To provide this background, the report will first explore the manner in which hydroelectric power is generated, and the components required in that generation. This will be followed by a treatment of the early development of electricity and its first commercial applications. Subsequently, the documentation focuses on southern California, where hydroelectric power came into its own in the 1890s and early 1900s, closely paralleling the population growth of the urban centers of Los Angeles, San Bernardino, and Riverside counties. The roles of the Edison companies and their predecessors in this hydroelectric development are also explored. All of these developments combined for the first time in the construction of Santa Ana River Powerhouse No. 1 and the subsequent elaboration of the Santa Ana River Hydro system. The final sections of the report address the Santa Ana River community at its peak in the 1910s and subsequent alterations to the hydro system.

Generalized Scheme of Powerhouse Operation

Hydroelectric power generation is based on two interlocking systems that are integral parts of any hydroelectric power plant. The first is the water system that provides the motive force; the second is the generation and transmission of electricity that has been created by that motive force. The first is far easier to comprehend than the second, but both must be explained in order to understand the function of a hydroelectric powerhouse. Toward this objective, the following section provides a generalized scheme of the water system that runs into, and the electrical system that runs out of, typical high-head powerhouses, such as those found along the Santa Ana River.

Typical High-Head Water System

In the eastern United States, where water is plentiful and elevation often lacking, a typical hydroelectric plant operates under relatively low water pressure. This is usually referred to as a low to medium head of water. Such plants are typically incorporated into low to medium height dams and use reaction turbines (Reynolds 1982). In the mountainous western part of the country, where elevation is easier to find than water, hydroelectric plants usually have high heads, or operate under higher pressure, and use impulse wheels (Rustebakke 1983:121). This is particularly true for southern California, where the height differential is great and the year-round water flow is minimal.

A high-head hydroelectric plant requires a tall column of water situated above the powerhouse in order to provide the pressure needed to spin impulse wheels. The purpose of the water system in any high-head plant is to provide this sort of pressure, and a great deal of preparation must go into the water system to make it operative and dependable. Water has to be taken far upstream from the powerhouse and transported by a conduit that will move the water toward the powerhouse. The grade of the conduit has to be just enough to move the water efficiently, and will be far less than the grade of the river bed. As the water nears the powerhouse, the canyon floor drops in elevation, leaving the conduit higher and higher up the canyon wall. By the time it reaches the vicinity of the powerhouse, the conduit water is hundreds of feet above the bed of the canyon. At this point, it enters a steeply angled metal pipeline for the final drop into the powerhouse. This is the basic principle of the water system used in a high-head plant. The specifics of such a system, and the terms used to describe them, are discussed below.

The water system begins with a diversion dam that funnels water into the conduit system. Where the water enters the system is referred to as the intake. Once in the system, water is transported along a conduit -- a narrow channel that may consist of any combination of wooden or metal flumes, pipelines, tunnels, and inverted siphons.

One of the most important components of the conduit is the sandbox, which is a small reservoir along the conduit in which the water is slowed sufficiently for sand to settle out. Such particulate material would be disastrous to an impulse water wheel and can be damaging to the conduit itself. For this reason, it is imperative that the sandbox be situated as close to the intake as possible in order to keep damage to a minimum. Many are equipped with gates and baffles so that one section can be closed off and cleaned out while water is rerouted through another section. Sand and other debris are removed through a series of apertures located at the base of the sandbox; just by opening these apertures, the sand that has settled to the bottom is cleaned out with the water. Another feature usually associated with the sandbox is the rock drop, which serves the same function, this time for small rocks that may have entered the intake. Auxiliary features along the conduit, usually found near the intake, are leaf rakes and fish screens. Most of these are revolving devices designed to keep floating leaves and large fish out of the conduit.

After the water has traveled the length of the conduit, it enters another small reservoir called the forebay, situated between the shallow grade of the conduit and the steeply graded pipeline that leads to the powerhouse. Additional leaf rakes and fish screens may be found here, as well as a series of gates needed to control the water flow. It is at the forebay that attendants in the powerhouse can micro-manage the flow of water into the pressure pipes (Wood 1914:455). If the flow of water into the powerhouse is shut off at the forebay, then the water that continues to flow through the conduit must be rerouted. Spillway pipes adjacent to the pressure pipes are provided for such instances, as are other spillways at various intervals along the conduit.

The pressure pipe, or the plunging pipeline that descends to the powerhouse from the forebay, is also referred to as the penstock. The penstock is a thick pipe of riveted steel segments capable of withstanding enormous pressure. In a high-head system, the penstock holds the water before it is released to the impulse wheels within the powerhouse itself. Generally speaking, the head is the elevation from the powerhouse to the forebay (Rustebakke 1983:29). Static head is the height of the water equilibrium within the penstock. In theory, this equilibrium should be at or just below the forebay, providing a solid column of water within the penstock that will exert powerful force when released in the powerhouse below.

In some cases, the penstock enters the powerhouse directly; in others, the penstock connects with a perpendicular pipeline that used to be called a receiver and is now known as a header. A receiver or header is commonly used when water from the penstock has to be divided to supply a number of generators within the powerhouse. Both receivers and penstccks are commonly equipped with shut-off valves to control the flow of water in the powerhouse (Hair, personal communication 1992).

Inside the powerhouse, the final pipes that leave the penstock or receiver are constricted to a point where a nozzle and needle can be used to direct a small stream of incredible force against the buckets of an impulse wheel. This is the most common application of force in a typical high-head powerhouse. It is also possible to run the whole flow of water through a reaction turbine. The main difference between the impulse wheel and the reaction turbine is that water strikes only a small portion of the impulse wheel at any one time, while the whole body of the water stream passes through a turbine. In the case of a turbine, water either exits from the outside of the wheel or from the inside. Inward flow turbines picked up the name of their nineteenth century inventor, James B. Francis (Allen 1958:529-530). The impulse wheel is typically used in high head plants because it responds better to fluctuations in the water load; a reaction turbine has greater efficiency only when the water load is at maximum capacity (Rustebakke 1983:114-115).

When water strikes an impulse wheel or passes through a turbine, the hydraulic system of the powerhouse intersects with the electrical system, creating its energy. Beyond this point, water exits the powerhouse through a tail race. In the case of powerhouses established in series, the tail race of the upper powerhouse enters directly into the conduit of the lower plant.

Basic Electrical System

Any device that converts mechanical energy (in this case water power) to electricity, is called a generator. A device that changes electricity back to mechanical power is a motor (Del Toro 1965:647). The generator, also known as a dynamo, is the focus of the powerhouse, and a number of devices converge on the generator to ensure its proper operation. Foremost among these mechanisms are the water wheel, the water wheel governor, and the exciter.

The motive force behind the water wheel has already been discussed. The water wheel powers the generator. If the water wheel and the generator are direct-connected, they are located on the same shaft and rotate at the same speed.

One of the devices that regulates the generator is the governor of the water wheel, which controls the speed of the wheel and, by extension, the generator itself. The governor prevents the wheel from spinning too fast, which can cause cavitation or the erosion of the metal parts of an impulse wheel caused by the partial vacuum created by high speeds. As a rule, however, impulse wheels are ideally suited for high-head powerhouses because the wheels tend to have a low specific speed: the high speed of the water and the low speed of the wheel tend to create a workable moderate speed for the generator (Rustebakke 1983:116).

Another device that helps regulate the generator, and in fact creates the electrical current, is the exciter. The exciter creates the electromagnetic force that has to interact with the wire coil. Because they have to create a consistent magnetic force, exciters must use direct current (DC), even if the generator is producing alternating current (AC). The electrical impulses of direct current travel in one direction only, from a positive to a negative source. With alternating current, the impulse oscillates in both directions along the line.

Even though exciters can be water-driven, with their own water wheels, they also require a series of DC batteries for regular use or for emergencies. Rheostats must also be used to control the DC voltage created by the exciters.

The generator itself is comprised of two basic parts, the stator and the rotor. As the name implies, the stator is stationary. The rotor is connected to the water wheel and revolves inside the stator. In many early generators, the electromagnets powered by the exciters were located on the stator, while current was generated on the rotor and picked up off the revolving shaft by a commutator. In almost all modern generators, the arrangement is reversed: the wire coils are stationary, while the electromagnets revolve, receiving DC current via slip rings (modern commutators). This modern arrangement is generally known as a rotating or revolving field generator.

Today a generator produces electric current by rotating electromagnets inside a coil of electrical wires located on the stator. Direct current from the exciter passes through a field breaker and onto the slip rings that energize the electromagnets. In the early days of electric generation, the function of the slip ring was performed by a commutator, which had a nest of conductive brushes that touched the axle of the rotor.

As the electromagnets or poles pass by the stator coils, the fields established by the magnets are interrupted, creating a cycle or voltage wave in the stator wires. Today, three separate wires (A-C), wound in the order of ABCABC, etc., pick up three different phases of each wave. This is known as three-phase or polyphase electric generation. There are two types of windings for polyphase generation, Delta and "Y." Delta is a simple three-wire configuration; "Y" is three wires and a ground (Myers, personal communication 1992). At present, almost all generators in this country are wound so that they create 60 waves or cycles per second. These waves create electrical impulses that are carried away from the generator on three separate wires of considerable thickness, sometimes identified as A, B, and C. These wires are designed to carry a current of relatively low voltage (pressure) but high amperage.

While still within the powerhouse, the three wires enter a circuit breaker and a bus disconnect. From this point, minuscule portions of the electricity are diverted to devices on the switchboard or circuit board, where the power is measured and controlled. Power can also be shut off at the circuit breakers.

Beyond the switchboard, the three wires are ready for the transformer, which is now usually situated in the yard around the powerhouse. Before they reach the transformer, however, just outside the building, the three wires intersect with the lightning arresters, which are located on long insulators or bushings. Metal cables from the arresters run down the building and into an extensive grid of underground wires. Since lightning has high voltage and relatively low amperage, lightning arrester wires do not have to be particularly thick.

Past the lightning arresters is the transformer, a static device with a magnetic core on which there are two or more windings in association but not direct contact. These windings, also known as induction coils, are insulated from each other and from the ground. The current enters the first set of windings with low voltage and high amperage, just as it came off the generator. The first set of windings then sets up another current in the second set of windings. If the second series of windings is tighter than the first, the voltage will be higher and the amperage lower in some inverse proportion. As a rule, the electricity that leaves the powerhouse transformer has high voltage and low amperage, and the wires are now considerably thinner. At high voltage, the current can travel great distances with considerable economy.

Beyond this point, the three wires carrying the high voltage current pass through a switchrack in the yard outside the powerhouse. The switchrack connects the power generated at the powerhouse with the one or more transmission lines that enter the electric service grid. The switchrack can be conceived as an electrical pool similar to a water reservoir: electric current from several potential sources mingles at the switchrack. The point of connection, known as a bus, consists of a series of conductive metal bars, with lines feeding in and out, each line equipped with a circuit breaker. These bars used to be copper, but are now usually aluminum, almost as conductive and far cheaper.

The switchrack allows the current to be shunted from one line to another so that breakers and transmission lines can be serviced as the occasion demands. Beyond the switchrack, the three electric wires of each transmission line continue to distant substations, where the voltage is stepped down by transformers operating in reverse. With low voltage and high amperage, the AC current is ready for customer use.

Summary

This basic outline of a typical water and electrical system of a hydroelectric powerhouse is as applicable today as it was at the turn of the century, when the Santa Ana River powerhouses were constructed. That is one very important reason why these powerhouses are still in operation. This is not to suggest, however, that these powerhouses were in any way typical or routine at the time they were built, for such was not the case. As Duncan Hay emphasized in his study of hydroelectric development in the United States, the years between 1895 and around 1915 witnessed rapid change and dramatic evolution in hydroelectric technology (1991:I:xi-xii). Beginning with the inauguration of the hydroelectric plant at Niagara Falls in 1895, the following 20 years were a period of remarkable innovation in hydroelectric design, water wheel configuration, and plant setting. Santa Ana River Powerhouse No. 1 is clearly representative of this innovative period.

In many ways, SAR 1 was more significant than the Niagara Falls plant that inaugurated the era of innovation. Many of the features of the Niagara plant were quickly outdated, such as external revolving-field alternators (electromagnets on the stators) and outward flow turbines (Hay 1991:I:24-25). This was not the case with SAR 1, which employed major technological features that became industry standards. Santa Ana River Powerhouse No. 1, in particular, broke new ground in hydroelectric powerhouse design and construction, both in the lay-out of its hydraulic system and in the innovations of its electrical generation and wiring. Both drew on developments that were new and almost untried at the turn of the century.

When SAR 1 went on line in early 1899, AC electricity had just come of age; 25 years before, commercial electricity as we know it did not exist. The rate of change in electrical technology during those 25 years is amazing even today. These changes must be examined in some detail in order to appreciate the achievement represented by the Santa Ana powerhouse system.

2. EARLY ELECTRICAL WORK

Period to ca. 1875

Electricity had been known and studied long before it was put to practical use or organized into a system of distribution for paying customers. The various properties of electricity had been examined since the late 1700s, almost 100 years before electrical development started to take off on its famous trajectory. The commercial electrical developments of the late 1800s were based on the theoretical discoveries of the first electrical scientists, who established the basic laws and the principles of electricity.

As early as the mid-1700s, Benjamin Franklin explored the nature of electricity with kites that attracted lightning. The ideas that Franklin espoused greatly aided the work of Alessandro Volta at the turn of the eighteenth and nineteenth centuries (Dibner 1964:17). In 1800, Volta created the voltaic pile, a series of metals and chemicals that produced an electrical charge. The voltaic pile was in effect the first battery, and it produced continuous current electricity that traveled along a line from a positive pole to a negative pole. This early form of electricity would later be known as direct current (DC). Volta's discovery was almost immediately communicated to the Royal Society in London, where it was quickly duplicated and improved upon (Williams 1971; Dibner 1962:1). As early as 1808, Sir Humphry Davy of the Royal Institution, using 2000 voltaic cells, created the first man-made electric arc that spanned the distance between two carbon electrodes (Hammond 1941:303-304). Although it was not known at the time, this would be the prototype of the first popular method of electric lighting, the arc lamp.

By the 1820s, the search was on for the connection between magnetism and electricity (Ross 1991). Danish scientist Hans Christian Oersted explored the properties of electromagnetic effect, but it was Michael Faraday who discovered the practical connection between magnetic fields and electrical currents (Williams 1971). By the early 1830s, Faraday discovered that he could create electric impulses by plunging a magnet into a coil of wire; electrical current was generated by keeping the wires and magnets in constant flux. This was the first generation of electricity by magnetism, and with this discovery, he had created the first dynamo or electric generator. Faraday also discovered the principle of electrical induction, the manner by which electric current set up in one coil could be transferred to another if the coils were adjacent (Dibner 1964:100).

By the time of Faraday's discoveries, the basis of modern electrical science had been established. Volta had found a way to produce a constant current source; Oersted had discovered the connection between magnetism and electric current; and Faraday generated electric current from the power of magnetism (Dibner 1962:57). The ramifications of these discoveries were soon probed and improved throughout western Europe and in the United States.

The first practical application of electricity came with the development of the telegraph in the 1840s. By the time of the American Civil War, the major cities of the eastern United States were connected by a network of metal wires on wooden poles over which messages could be relayed by means of a weak electric current. After the war, in 1866, the first successful trans-Atlantic telegraph cable was laid from Ireland to Newfoundland (Jarvis 1958b:226). In the 1870s, the communication network tightened with the invention of the telephone. All electrical systems for telegraph or telephone operated with direct current (DC), where electrical current passed in one direction along a wire or circuit from the positive pole of a battery to the negative pole. Alternating current (AC) was known, but its use was very limited.

By this time, the basic measurements of electric current began to receive the names that are used today. The units of measurement were named for late eighteenth century and early nineteenth century inventors and electrical physicists: watts, volts, ohms, and amperes. The term "ohms" was first proposed in 1861 and was universally accepted 20 years later at a congress of electrical scientists in Paris (*Oxford English Dictionary* 1980:1982). "Volts" was used in the modern sense by the 1870s (Ibid.:3654). "Amperes" was adopted at the same 1881 Paris Electrical Congress that first designated ohms. The use of the term "watts" was first proposed the following year, in 1882, and was adopted later that year by the British electrical community (Ibid.:73, 709). From Britain, the term spread quickly throughout Europe and America.

An "ohm," named for German physicist Georg Ohm, measured the resistance of a conductor during the transmission of an electrical current. "Volts," named for Volta, measured the pressure or "voltage" of the current. "Amperes," named for the Frenchman Andre Ampere, measured the current itself. Volts and amps were discovered to be inversely proportional in any electric current, as first formulated in Ohm's Law (Hamilton, personal communication 1992). Finally, "watt," named for Scotsman James Watt, was adopted as a unit of electrical power. It is the rate of work represented by a current of one ampere under the pressure of one volt, or 1/746th horsepower (*Oxford English Dictionary* 1980:3709; *Webster's* 1963:1008).

Such definitions mean little to most laymen today, and probably meant less to people in the nineteenth century. For this reason, these properties of electricity were often compared to the different characteristics of flowing water. Amperes measure the quantity of electrical flow, like gallons per minute measures the flow of water. Volts measure the force of the electrical current.

It would be comparable to water pressure in a pipeline; the greater the pressure, the greater the force pushing it through the pipe. Ohms would be the friction or resistance created by the pipe itself, resistance that would have to be overcome by the pressure or volts. Watts measure the usable force that can be obtained from an electrical current, like the horsepower rating of a steam engine or water wheel (Hair, Hamilton, personal communications 1992; Myers 1990:58). While terms like watts, volts, and amps became current within the scientific community, it must be remembered that for many years, well into the twentieth century, more traditional terminology remained popular. Watts, for example, did not completely supplant "horsepower" until the 1920s (Myers, personal communication 1992).

For most of America in the early 1870s, even analogies with flowing water were moot points. For the general public, electricity hardly existed. Practical mechanical force was provided by steam engines located in factories. Aside from railroad locomotives, which were steam engines put on wheels, transportation was still based on the horse. Artificial lighting was limited to the kerosene lamp or maybe gas lights. There were some 500 horse railway companies in American cities, with a combined total of 120,000 horses and 25,000 cabs. The newest innovation in lighting was gas, which provided street illumination in the larger cities and interior lighting service in many homes (Hammond 1941:3-4).

In the early 1870s, electrical dynamos were curiosities powered by reciprocating steam engines. Such engines were almost universal by the mid-1800s and were no more than 30 to 35 percent efficient; some operated as low as 5 percent (Myers 1990:3-4). Throughout the 1860s and 1870s, efficiency levels were not a major concern, if only because steam engines had a relatively small day-to-day impact on the lives of most Americans; their use was essentially limited to railroad engines and large factories. There was no way to transport this mechanical energy except directly with gears and shafts, as was common in Europe, or a system of hide and canvas belts, as was common in the United States. To overcome this deficiency, steam engines grew to enormous size, but there was still no way to transport the energy they created beyond the confines of a single building.

All of this would begin to change in the mid-1870s with the development of new dynamos and the spread of arc lights. These initial steps in the commercial exploitation of electricity were based on discoveries that were already decades old, but they quickly lead to new discoveries and applications that were truly revolutionary. The 25-year period between 1875 and 1900 was a time of innovation in electrical generation, a period that witnessed the evolution in electric applications from arc lights powered by direct current, to incandescent lamps and induction motors powered by alternating current. Santa Ana River Powerhouse 1 occupied a significant place in the development and transmission of electrical power near the end of this 25-year period.

Supremacy of Arc Lights, 1876-ca.1879

At the Centennial Exposition in Philadelphia in 1876, there was a small display of electric lighting: two bluish arc lights, each powered by its own dynamo. The arc lights were carbon rods kept a certain distance apart, with the light provided by the electric current itself as it jumped from one carbon to the other. This light was protected by open-ended glass globes positioned between the carbon electrodes. The two dynamos had been perfected on different continents. One was Belgian; the other American (Hammond 1941:7).

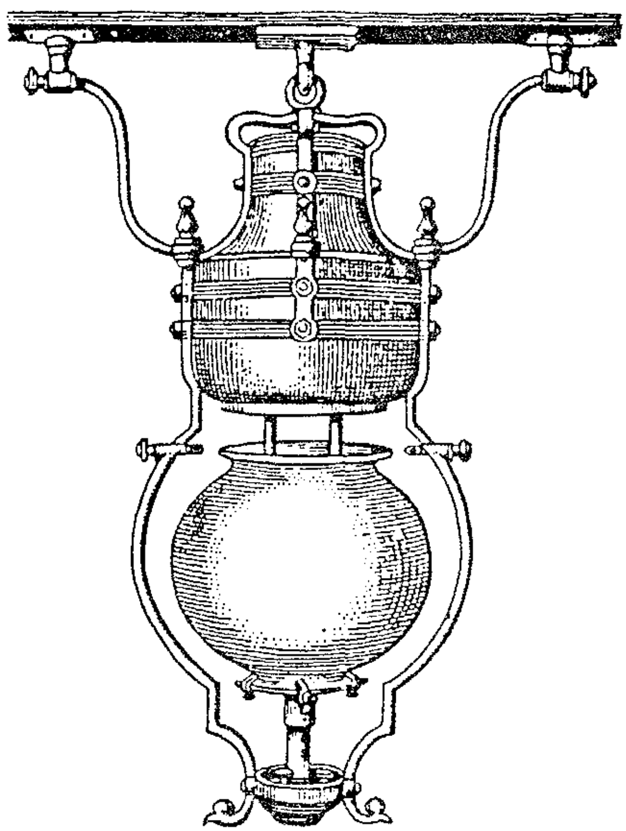
The Belgian dynamo was the more famous of the two, and had been designed by Zenobe Gramme as early as ca. 1870. Gramme's dynamo was in fact the first practical generator. It had a ring armature, which was a coil of insulated soft-iron wire, around which was wrapped another coil of insulated copper wire. This armature rotated between two magnets, and the electric current was picked up off the armature by a commutator (Jarvis 1958a:188-189). This was the basic configuration of most earlier dynamos, which had been around since the 1840s (Dunsheath 1962:104).

The Gramme dynamo popularized the idea of stationary magnets and revolving armatures as a standard for electrical generators. The ring armature was later followed by the drum armature, with wires wound around a drum rather than an inner coil of wire. All of this led to the standardization of the disk armature, where windings were placed on the rotor portion of the generator (Jarvis 1958a:189-190,193).

All this had taken place just a few years before the Exposition. During this period, the only practical use of electric current had been in the realm of electroplating, even though a few arc lights had been installed in European lighthouses (Dunsheath 1962:104-106; McMahon 1984:20). In 1876, arc lights were still novelties that were completely overshadowed by the enormous steam engines of the day. This, however, would begin to change with the work of Charles Francis Brush (Myers 1991b:22) who would transform dynamos and arc lights into a successful commercial venture.

Between 1876 and 1878, Brush perfected arc lights in series, with the financial backing of the Cleveland Telegraph Supply Company (Figure 3). These arc lights ran off the same current, with a short-circuiting mechanism that would route electric current around disabled lamps and still light the rest. Brush brought this invention to the fore in Cleveland, which was soon fascinated by the arc light (Hammond 1941:9). Soon, arc lights lit up individual businesses, with each system powered by its own dynamo, often located in the basement.

Figure 3. Brush Arc-Lamp, ca. 1880
(Jarvis 1958b:215)



The first municipal use of arc lights occurred in Cleveland in April 1879. Street lights were installed on 18-foot posts, and powered in series by a Brush dynamo in the Cleveland Telegraph Supply shop. Monumental Park was lit with arc lights placed on tall masts and towers (Hammond 1941:27-28).

The Brush system arrived in San Francisco just two months later, in June 1879. Not only was it one of the first arc light systems in the United States, it was by far the earliest such system on the West Coast. The San Francisco Brush system was operated by the California Electric Light Company, organized by George Roe and William Kerr, who had the Brush territorial license for the West Coast (Hammond 1941:28-29). The California Electric Light Company installed an arc lighting system of 21 masts, each 50 feet high with an illumination measured at 4000 candlepower (Hammond 1941:29).

The California Electric Light Company was also possibly the first in the world to propose selling electric power to general customers from a central dynamo. Before this, all illumination had been for private use, with each paying customer forced to obtain a dynamo. With the new system of selling electricity came new problems. Since electric meters were unknown, customers were charged a flat $10 fee per lamp per week. Later, rates were adjusted for the time the lamps were extinguished on weekday evenings. There was no current whatever on Sundays and holidays (Hammond 1941:29).

In July 1879, the city of Niagara Falls, New York, was illuminated with 16 Brush dynamos and arc lights in series. The dynamos were driven by water wheels, which made it a pioneer hydroelectric plant (Hammond 1941:30).

The first town to be lit solely by electricity was Wabash, Indiana, in 1880, after the municipal government found it would be cheaper than gas. The town installed four arc lights of 3000 candlepower each, with each light mounted on crossarms above the courthouse (Hammond 1941:31-32).

By the time Brush systems were being installed, further work was being done on other aspects of the electrical system. One of the drawbacks of early electric generation was the size of the dynamo. Most were huge, with an average weight of 600 pounds, and an efficiency of about 30 percent (Hammond 1941:12-13, 17). James J. Wood of the Brady Manufacturing Company of Brooklyn designed a new dynamo in 1879 that weighed only 87 pounds. Rights to this innovation were bought by the Fuller Electric Company, which renamed itself the Fuller-Wood Company. The company proved very successful, with Wood's new dynamo as their main product (Hammond 1941:17-18).

Other electrical work was conducted by Elihu Thomson in the late 1870s. Thomson designed a regulator for the dynamo that could permit individual lights in an arc light series to be turned on and off. By 1880, Thomson and his assistant, Edwin Rice, had situated themselves in New Britain, Connecticut, where they created their own firm, the American Electrical Company. Shortly after this, Thomson determined that a magnet could be used to break an electrical circuit. This was first used to develop a lightning arrester, and was later applied in the development of electrical switches (Hammond 1941:33-36).

By around 1880, arc lights were also being installed for illumination in large buildings like factories, hotels, and theaters -- the sort of buildings that would benefit from a few sources of intense light. Of course, the exposed electric current of the arc light posed a constant danger, which made indoor applications of the system too dangerous for most homes. They were also too heavy, often weighing 130 pounds apiece. The carbons at either end of the exposed current had a relatively short life span, about 4.5 hours, and had to be adjusted frequently (Hammond 1941:19; Myers 1991a:4).

The problems of interior lighting emphasized the deficiencies of the arc light system for general indoor use. A method had to be found for subdividing the electric current that provided one enormous source of illumination into one that could produce a greater number of smaller lights for the same total power (Hammond 1941:19). The development of the incandescent light bulb was the answer to this problem, and it would be only one of the great achievements of Thomas Alva Edison.

Edison's Achievements, 1879-1886

Thomas Edison invented the first successful incandescent lamp just as the limits of arc lighting were being reached. By October 1878, he had incorporated the Edison Electric Company with monies from interested backers, and devoted the energy of this firm to the creation of a small-unit electric light. This research was conducted at Edison's headquarters in Menlo Park, New Jersey (Hammond 1941:21).

It was determined that this incandescent light bulb would have to contain a lamp filament of carbonized material hermetically sealed in a vacuum. By October 1879, Edison succeeded in carbonizing cotton thread. After bending it to shape and placing it in a vacuum bulb, it was ready for testing. The first successful incandescent bulb was energized on 19 October 1879 and burned for 40 hours (Hammond 1941:21-22). Subsequent experiments extended the life of the lamp several times over (Figure 4).

The advantage of incandescent lamps over arc lighting was realized almost immediately. Arc lights had a constant amperage, but operated with a pressure that could be as high as 2000 volts. Edison's incandescent lamps reversed that situation, with a constant voltage (around 110 volts) and an amperage that varied (Hammond 1941:101). Because incandescents could be run on lower voltage, they were inherently safer for interior use. As a result, they were the first electric lights that could really compete with gas in the market of home lighting (Hammond 1941:23).

Figure 4. Early Edison Lamps
(Jarvis 1958b:220)

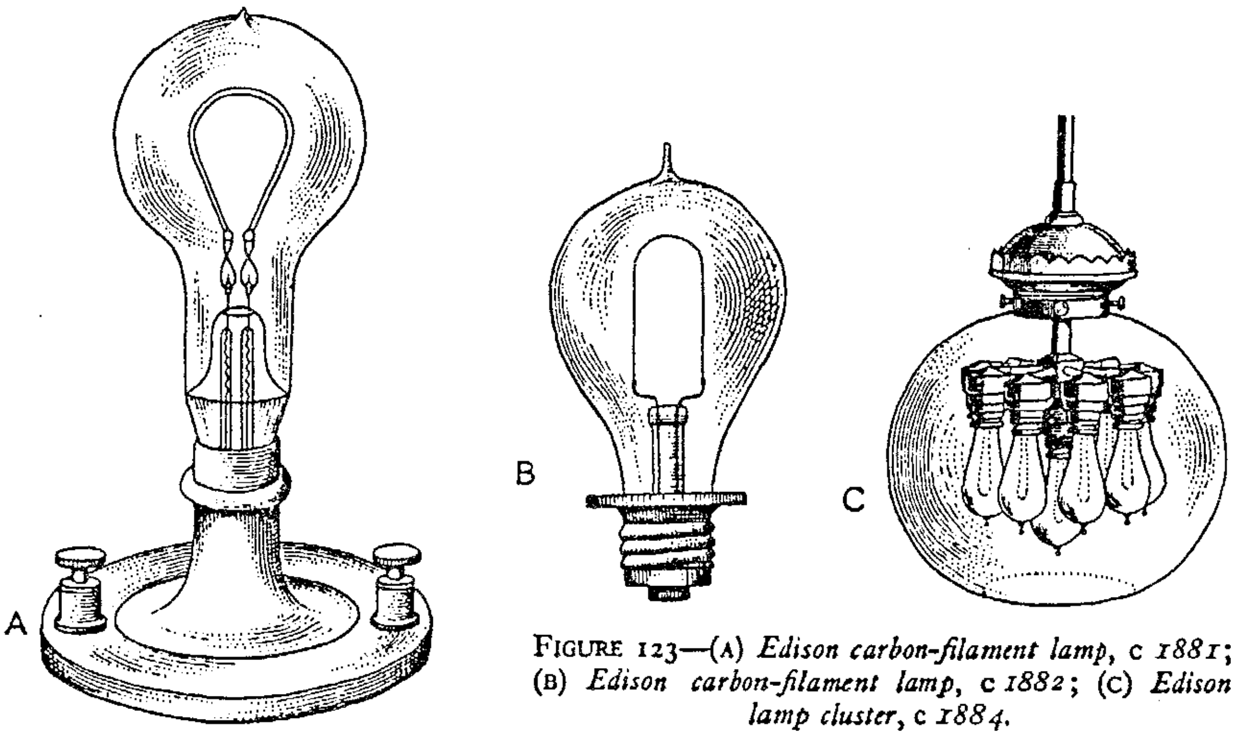


FIGURE 123—(A) *Edison carbon-filament lamp,* c *1881*; (B) *Edison carbon-filament lamp,* c *1882*; (C) *Edison lamp cluster,* c *1884.*

The incandescent lamp led to the development of auxiliary inventions. Because the amperage was high on incandescent lamps, the current became more difficult to break. This led to the development of new switches (Hammond 1941:101). By the 1880s, switching mechanisms were put onto a single frame or "switchboard." The earliest boards were made of wood and could burn if the current was not properly controlled. All of this led to the development of the Edison Switch, which was the first knife-blade switch that later became the industry standard (Hammond 1941:100-102).

The growing popularity of incandescent lamps led to the search for filaments superior to carbonized thread. Bamboo filaments were found to be more durable and became the standard for a number of years. Edison also continued to experiment with wire insulation in order to improve the efficiency of his electrical system. All of this led to the very successful Edison Lamp Company, organized to market the incandescent lamps (Hammond 1941:37-39, 43-44).

Edison was also working on a new dynamo concurrently with the development of the incandescent lamp. Convinced that dynamos could be made more efficient, he made his machine with large magnets, some up to 3.5 feet tall and joined at the top by a conductive cross-piece. Edison's dynamo looked like a large Roman numeral II. Formally named bi-polar dynamos, they were nicknamed "long-waisted Mary Anns." This model had a drum-type armature fashioned of individual sheets of iron insulated from each other and mounted on a single shaft. Subsequent tests showed that this dynamo had an efficiency rating of 90 percent (Hammond 1941:23).

With the success of the incandescent lamp, Edison moved almost immediately to a project of enormous complexity, a plan to light lower Manhattan with incandescents and underground DC power lines. To effect this, the Edison Electric Illuminating Company of New York was chartered in December 1880. Edison and his staff moved out of Menlo Park and for the next two years devoted themselves to this project in New York City. There was some sense of urgency, for even as this research continued, a Brush system was being installed on masts along Broadway by the Brush Electric Light and Power Company of New York (Hammond 1941:40-41; Rustebakke 1983:10).

Edison faced enormous problems in the installation of his Manhattan electrical system, which required a level of care and wiring expertise that had not been needed with arc lights. He had to invent most of the materials he needed and supervise the manufacture of the tubing, lamp sockets, switches, meters, fuses, and a galaxy of other related materials. These sidelines led to new Edison Companies, such as the Edison Machine Works and the Edison Tube Company (Hammond 1941:42-43).

One of the most serious problems Edison faced was the drop in voltage that seemed to occur with such a large system. The traditional means of correcting this was to have incredibly thick conducting wires at the beginning of the system. This project, however, was so large that such wires, if made out of copper, would be prohibitively expensive. This dilemma led to the invention of the feeder system of current distribution. Until then, most distribution systems had direct current running from the dynamo to the first light, then the second light, and so on. With the feeder system, feeder lines ran from the dynamo to central points in a parallel circuit to help equalize the current throughout the entire system (Hammond 1941:45-46).

Another Edison innovation was the three-wire system, which saved copper and improved the electrical flow. The three-wire arrangement used only one wire for the return of the electrical current, rather than the previous use of two (Hammond 1941:59). Edison also did work on the so-called "jumbo dynamo," which was a large generator powered by a high-speed steam engine. In the past, most stationary engines had operated with 60 revolutions per minute (rpm) and had pressure of 60 to 80 pounds. Edison's new steam engine aimed for 600 rpm and a pressure of 120 pounds (Hammond 1941:44).

When Edison's Manhattan system was ready for operation in September 1882, the dynamos were in position at his Pearl Street Station, the center of the new distribution system. This was the beginning of the electric utility industry, and it opened by serving 59 paying customers within a square mile area. By the end of the first year, the number of customers was up to 439 (Rustebakke 1983:1). Soon, the system covered 900 buildings and powered 14,000 incandescent lamps (Hammond 1941:46-47).

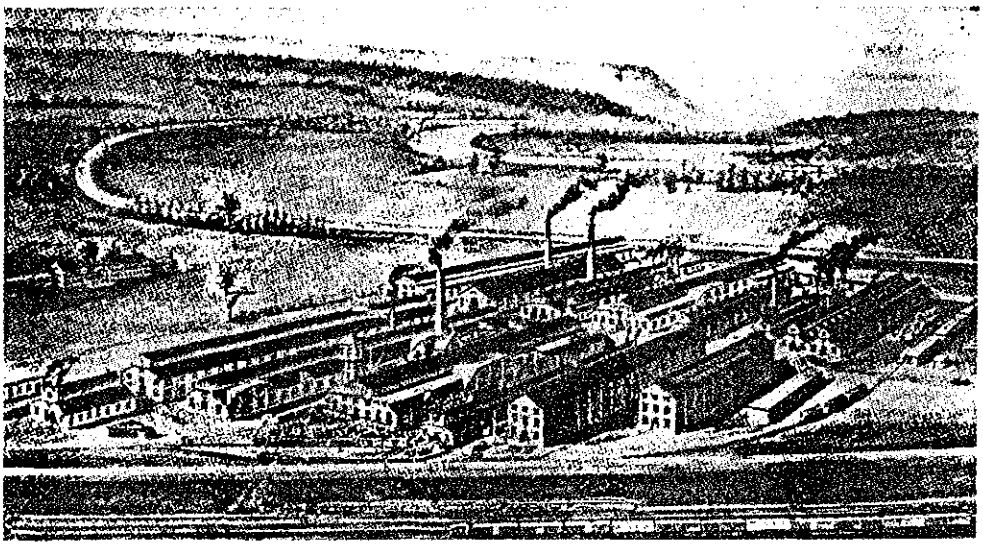
By the mid-1880s, Edison was a major force in electrical generation, not only in New York, but throughout the eastern United States. His companies offered isolated or private generators for large businesses, as well as his new central station plants, which became his preferred mode of operation (Hammond 1941:65). By 1883, he had licenses to start distribution systems in other cities, and had also developed plans for bringing electricity to rural areas with overhead wires strung on poles, tentatively identified as the "village plant system" (Hammond 1941:59).

By 1885, the Edison Machine Works shop in New York City was becoming too cramped, and Edison dispatched assistants to look for a new location somewhere in New York, New Jersey, or Pennsylvania (Hammond 1941:113). In 1886, Schenectady, New York, was selected as the new headquarters of the whole Edison operation, and within a couple of years, a sleepy Dutch town in the Mohawk Valley became one of the great industrial centers of the American Northeast. By the late 1880s, Schenectady was the home of Edison Machine Works, the Edison Tube Company, and the Edison Shafting Company, among others. Most of these were merged with the Edison Machine Works by the end of the decade (Hammond 1941:149). By this time, the Edison complex had grown to 26 buildings employing about 800 people who manufactured everything from Edison dynamos and Sprague electric motors, to insulated wire (Hammond 1941:151; Figure 5).

Direct Current and the First Motors

By the 1880s, electricity and electrical systems were known around the world, and American companies led the way in both discoveries and systems service. This period also saw the growth of the type of central stations championed by Edison (Hammond 1941:91). In 1884, Edison issued licenses for 20 different local electric companies, mostly in Massachusetts, Pennsylvania, and Ohio. In 1885, the number of new licensees was 31; in 1886, 48; the following year, 62. Thereafter, the number simply mushroomed, with all of these companies using incandescent lights, Edison patents, and direct current (Rustebakke 1983:1-2). Even so, electricity was still limited to the population centers in the Northeast and Midwest, and a few isolated spots along the West Coast.

Figure 5. The Edison General Electric Company, 1891
(Hammond 1941:opp. 151)



THE EDISON GENERAL ELECTRIC COMPANY—1891
The Schenectady plant the year before Edison and Thomson-Houston joined forces to form the General Electric Company. In the background can be seen the Mohawk River and the Erie Canal.

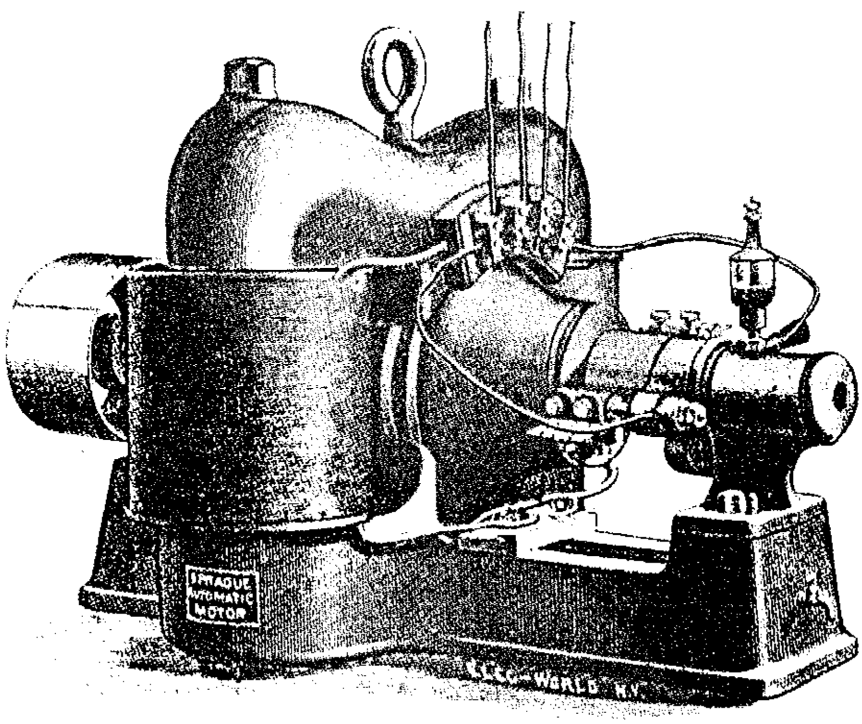
Even though Edison seemed to dominate the decade, his companies did not lack competition. The old Brush system of arc lights persisted for several years in the early 1880s; the Thomson-Houston electrical system was considered by many to be more fully self-regulating than the Edison system (Hammond 1941:49-50). In 1884, George Westinghouse established the Westinghouse Electric and Manufacturing Company, which would prove one of Edison's strongest competitors (Hammond 1941:106).

In short, the 1880s were a rather confusing time in which there was very little standardization of equipment, electrical transmission, or systems of distribution. Brush dynamos competed with the four different sizes of the Edison bi-polar dynamos; Thomson-Houston dynamos competed with those made by Wood (Hammond 1941:72). Arc lights competed with incandescents, and isolated generator systems competed with central power plants. The only thing that seemed to be standard was the general use of direct current -- and even that would not survive the decade.

In the meantime, the greatest application of direct current came with the development of electric motors and the electric street cars that motors made possible in the mid-1880s. A number of experimental street car systems were in the making (Myers, personal communication 1992). One of the first of these began operation in Cleveland in July 1884; its success was based on dynamo reversibility. Understood in principle since around 1875, dynamo reversibility led to the first successful electric motors for street cars. The principle was rather basic: after the steam engine powered the first dynamo, which made the electric current, there would be a second dynamo on the same circuit that would work in reverse, and thus act as a motor that would create mechanical energy (Hammond 1941:79).

Soon DC motors were created for uses other than transportation, many developed by Frank Sprague, who had been designing prototypical motors since the early 1880s (Hammond 1941:62-63). By the mid-1880s, Sprague had perfected a motor that was endorsed by the Edison Electric Light Company (Figure 6). The new motor worked well with the Edison system of central station power and was capable of being turned on and off while the current remained on (Hammond 1941:115-17). By 1886, Sprague had formed his own company, and by the end of that year, had installed 190 motors throughout cities in the East and Midwest. These motors performed a wide assortment of functions, running shoe manufacturing machinery, coffee mills, emery wheels, lathes, printing presses, ventilators, and even ice cream freezers (Hammond 1941:118-19).

Figure 6. Sprague Electric Motor
(Hammond 1941:opp. 98)



THE ELECTRIC MOTOR DEVELOPED BY FRANK J. SPRAGUE

Sprague was involved in the street railway business, as well. He personally designed and supervised the construction of the Richmond, Virginia, street railway system in the late 1880s (Hay 1991:I:35). The Richmond system was the first commercially successful street railway in the United States (Myers, personal communication 1992). One of the innovations of this project was the replacement of the old copper brushes on the commutator with carbon brushes that did not spark and wear out as frequently (Hammond 1941:135-136).

Despite the success of the Sprague motor, the company that made them never achieved much financial success. By the end of the decade, the Sprague Company was absorbed into the Edison family (Hammond 1941:157). This only helped the distribution and use of electric motors. These motors, which ran on direct current, were easy to start and stop, could operate at various speeds, and could take incredible abuse, as witnessed by the development of the street railroad systems (Myers 1990:13).

The development of motors in the 1880s took electricity beyond the realm of lighting and into the world of motive power. Soon electric companies had to stay open throughout the day, rather than simply operating at night (Hammond 1941:151-152). By this time, the development of electricity was pushing up against the limits of direct current transmission. Ironically, the spread of incandescent lamps exacerbated this problem. With arc lighting, the transmission of DC power was possible for distances up to at least 10 miles, since arc lighting systems operated at relatively high voltage. Even that voltage, however, could not be raised much higher for transmission over longer distances. As far as transmission was concerned, the spread of incandescents was a step backward for DC power. The lower voltage current used in the incandescent lamp systems could only be transmitted about three to five miles with any ease. Greater distances required greater amperage and larger wires, and the copper costs for such alterations were prohibitive (Hammond 1941:107; Myers 1990:14, 1991b:23).

The solution was already at hand by the end of the decade. Struggling for primacy and subjected to the scorn of Edison and his researchers, was a wholly new method of electrical generation that exhibited traits of almost incredible flexibility This new innovation was alternating current, which quickly became and remains today the cornerstone of electrical generation.

Development of Alternating Current, ca. 1885-1890

By the middle to late 1880s, the Edison companies were confronting the limitations of direct current. With heavy investments in direct current technology and transmission systems, they were loathe to consider a totally different method of transmitting electric current. Others without the commitment of such investments were quick to see new avenues. There were even incentives for the newcomers to do so, since new inventions could free them from the constraints of Edison's numerous patents. This was the situation that propelled the research and development into alternating current.

Direct current impulses flow in a single direction, from a positive charge to a negative charge. The great advantage of DC in the early days of electricity was that DC energy could be stored in batteries, which made it very economical when electric generators broke down, as often happened (Dunsheath 1962:158). Alternating current impulses oscillate back and forth along the same line at established intervals. This feature is so important that early AC generators were often referred to as alternators. The rate of alternation was known as the "frequency." This alternation gives AC a certain flexibility that direct current does not have. AC voltage can be stepped up (and the amperage reduced), enabling it to be transmitted longer distances. High voltage wires do not have to be thick, as is the case with high amp wires, and this alone saved money over the typical DC system.

Nikola Tesla is generally credited with the development of the first alternating current generator and motor in the United States. The advantages of this new AC system were already understood in Europe, and other researchers quickly sought to improve on Tesla's work (Jarvis 1958b:231; Myers, personal communication 1992). At that time, all alternating current was "single-phase," which meant that only one burst of electric energy was picked up from each encounter with the electromagnet (Myers 1990:14, 1991:23). Single-phase AC only required a single pair of wires out of the generator, just as with DC power. The difference was that AC voltage could be dramatically increased in order to lengthen the transmission distance.

The device that stepped up voltage or could step it down, was first known as an induction coil, but was quickly dubbed a transformer or converter (Hinson 1956:8). All were based on the principle first established by Faraday that current created in one set of coils could be "transferred" to another parallel set of coils through induction. The ratio of the windings in one coil to the other determined whether the voltage would be stepped up or down, and to what degree. If AC power was to develop its full potential, it had to develop together with transformers.

Practical transformers were developed in the United States by William Stanley, with the financial backing of George Westinghouse, who had set up his own company in Pittsburgh (Leupp 1919:131). In 1885, one of Westinghouse's assistants was in Europe on personal business and saw an experimental AC system near Turin, Italy. He cabled this information to Pittsburgh, and Westinghouse cabled back instructions for the assistant to purchase an option on the

American rights to the patent, held by Lucien Gaulard and John Gibbs. The deal was quickly transacted. Before the end of 1885, many of the Gaulard and Gibbs devices and a Siemens alternator had arrived in Pittsburgh (Cope 1936:3-4).

It was already apparent that Gaulard and Gibbs had a distribution system using rather primitive transformers. Stanley, then employed by Westinghouse, immediately concentrated his energies on the transformers. His work led to the creation of a parallel system of distribution, which was a great improvement over the old Gaulard and Gibbs system. This complemented work that he had already begun in the summer of 1885 on a transformer of his own. The improved Stanley transformer was wound for 500 volts in the primary coil and 100 volts in the secondary (Leupp 1919:135; Cope 1936:3-4).

Due to health problems, Stanley had to move from Pittsburgh to Great Barrington, Massachusetts, by the end of 1885. At Great Barrington, Stanley worked to perfect his transformers with Reginald Belfield, former electrician with Gaulard and Gibbs. He still kept ties with Westinghouse, who had rights to any inventions he might produce based on the Gaulard and Gibbs patent (Cope 1936:3-4). In 1886, Westinghouse came out with his first transformer patent, based on work by Gaulard and Gibbs, and Stanley. By 1887, Westinghouse had patented the first oil-insulated ventilated transformer coil (Cope 1936:6; Figure 7).

Work also continued on AC generation. In November 1886, the first commercial AC generator was installed into a previously established Brush system in Buffalo, New York (Cope 1936:5). This single-phase generator had 16 poles or electromagnets and made 1000 revolutions per minute, 16,000 alternations per minute, which translated into 133.33 cycles per second (Hinson 1956:3). This generator powered incandescent lights, rather than motors.

Soon Westinghouse took out a patent for single-phase AC motors. These were the first practical induction motors, created around 1887 and based on the earlier Tesla model. They operated on the principle of electro-induction repulsion, whereby magnets were alternately attracted and repulsed under the influence of alternating current. Due to this alternating attraction and repulsion, the armature of the motor would revolve, providing mechanical force (Hammond 1941:145-146).

The further development of single-phase AC motors quickly led to problems. Early AC power was generally geared for lighting, which did well at the prevailing high frequency of 133 cycles (Cope 1936:7; Myers 1991b:23-24). The high frequency ideal for lighting was rather poor for motors, which operated best at around 20 to 30 cycles. This eventually led to a frequency compromise of around 50 to 60 cycles that was found to be satisfactory for both lights and motors. It is a compromise which still survives.

Single-phase AC motors had a much more serious problem than frequency adjustments. Unlike DC motors, they could only be operated if they were fully synchronous with the powering generator. They could not be started and stopped independently of the generator (Myers 1991b:23-24). It usually took about three to five minutes to start the motor, and it was a difficult process. Single-phase AC motors were not much competition for the older DC motors (Myers 1990:28-29, 1991b:25).

Figure 7. Early Transformers
(Cope 1936:6)

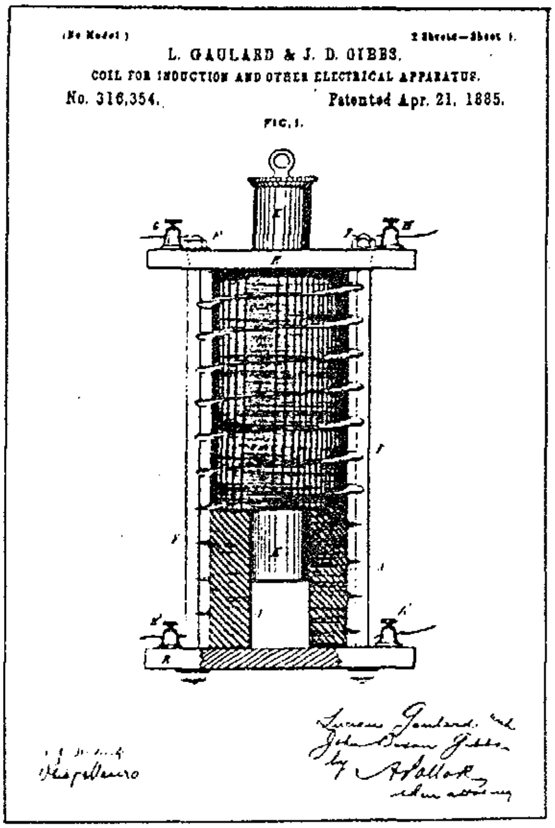


Fig. 1

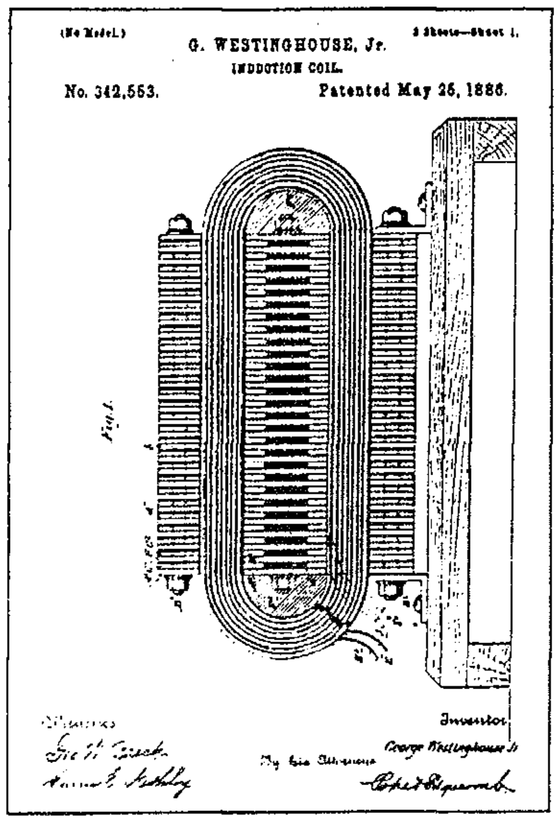


Fig. 2

Fig. 1—The original Gaulard and Gibbs transformer patent was registered in the United States.
Fig. 2—The principal drawing in the first transformer patent granted in the United States.

Serious competition with the DC motors only began with the development of the polyphase AC motor. Also known as multi-phase, polyphase was generally synonymous with three-phase AC electricity. Although four-phase AC existed, it was never popular (Myers, personal communication 1992). The patent for the first three-phase AC motor was issued to Nikola Tesla as early as 1888. Westinghouse quickly secured the American rights to this patent. The initial problem was that no commercial generators in this country could create polyphase electric current. After this was resolved, the first commercial use of a polyphase AC motor in the United States occurred at Willock Station, near Pittsburgh, in September 1889 (Cope 1936:7-8).

The first AC transmission line in the United States was erected in 1889 between Oregon City and Portland, Oregon, a distance of 13 miles. At Oregon City, two 300-horsepower water wheels powered a single-phase AC generator, which had a capacity of 720 kilowatts. The current was transmitted to Portland at a pressure of 4000 volts (Rustebakke 1983:2). No transformers were used to raise the voltage (Myers, personal communication 1992).

By 1890, AC electric power had arrived, even though it was more commonly single-phase than polyphase. AC power and the motors it ran were aggressively marketed by Westinghouse and the Westinghouse spin-off companies. Foremost among these were the Stanley Laboratory Company and the Stanley Electric Manufacturing Company, formed by William Stanley, Cummings Chesney, and John Kelly in 1890-1891. The Stanley companies built transformers and promoted the virtues of AC. They also manufactured a complete line of AC machines, commonly known as the "SKC system" (Hammond 1941:177-178).

By around 1890, Westinghouse was working on a two-phase AC system that was considered easier to adapt to pre-existing DC lighting circuits. By 1891, Westinghouse engineers were recommending the use of 30-cycle, two-phase alternating current (Hay 1991:I:19). Even though this system did not prove ultimately successful, it helped popularize the use of AC over direct current.

Elihu Thomson and the Thomson-Houston Company also participated in the development of AC power and transformers. In 1887, Thomson received a patent for a transformer that was encased in mineral oil that was both insulated and cooled. This marked the gradual end of the air-cooled transformers, which had been standard up to that point (Hammond 1941:238-239). It was harder to break an AC arc than had been the case with DC, and this led to the perfection of the oil switch, which reduced the length of the current arc before it could be broken. The elaborate switch mechanisms now required soon led to the development of the circuit breaker (Hammond 1941:267). By 1888, an induction meter capable of measuring ampere-hours, as well as a watt-hour meter, were invented by Shallenberger (Cope 1936:6).

By the late 1880s, the development of electricity was in incredible flux, both in the number of inventions and the marketing of electrical systems. Development was proceeding at such a pace that the Patent Office could barely keep track of the innovations and often made mistakes. With so many independent researchers coming to similar conclusions and patenting the results, there was a serious overlapping of both patents and ideas (Hammond 1941:141).

Almost inevitable was the so-called "War of the Currents" waged between the Edison companies, which were anti-AC, and the Westinghouse operation, which was strongly pro-AC (Hammond 1941:108-109). During this period, Edison's DC system was entrenched in the larger cities and favored by the largest businesses. Edison claimed that AC was too dangerous for general use because of its "high pressure" (Cope 1936:5). AC was just as strongly advocated by Westinghouse, Stanley, and Elihu Thomson.

The War of the Currents was waged not just in America but throughout the electrical world (in Britain, it was known as the Battle of the Systems). In Britain it was a war of words and opposing economic arguments; in the United States it was more devious. For example, an electrical consultant associated with Edison, Harold Brown, sponsored the use of AC as the legal means of electrocution in the state of New York, even to the point of obtaining Westinghouse alternators for this purpose in 1889. Brown then waxed eloquent in seminars on the dangers of alternating current because it had been chosen over DC to execute criminals. Westinghouse, for his part, considered filing charges for conspiracy (Jarvis 1958a:200-201; Leupp 1919:145-147).

Consolidation of Electrical Companies, ca. 1889-1892

In the early days of electrical discoveries, most researchers were too busy to defend their own patents or attack those of others. By the late 1880s, there was too much investment at stake to overlook such matters. The most critical issue of that time was the battle over Patent Number 223,898, granted to Edison in 1880 for the incandescent lamp. By the end of the decade, incandescents were so popular that other companies wanted a share of the market. The Edison Electric Light Company took U.S. Electric Lighting Company to court in 1889 for patent right infringement. This turned into an enormous case that dragged on for three years (Hammond 1941:179-184). It was closely watched by all of Edison's competitors, since almost everyone had an incandescent lamp on the market, and an Edison victory could wipe out all of these developments and give Edison a renewed lock on the electrical market.

This was also a period of regrouping for Edison, which had been stung by the electrical developments of recent years, particularly in the realm of AC generation. The first step in this period of consolidation was the amalgamation of the larger Edison manufacturing companies, which were merged in 1889 into the Edison General Electric Company, based in Schenectady, New York. The companies that were merged included, among others, the Edison Electric Light Company, the Edison Machine Works, and the Edison

Lamp Company. Subsidiaries were also bought out, such as the Canadian Edison Manufacturing Company and the Edison United Manufacturing Company. Thomas Edison himself began to move away from the business end of the operation to concentrate on inventions, like new filaments and glass globes for the incandescents (Hammond 1941:156).

Other companies also began a period of consolidation. Foremost of these was Thomson-Houston, which began to suggest mergers with some of its competitors. In 1889, Thomson-Houston bought controlling stock in the old Brush Company of Cleveland, enhancing their position relative to Edison (Hammond 1941:162-3).

Finally, in 1891 and again in 1892, the Edison patent on the incandescent lamp was sustained. The outcome of the court case was both a blessing and a warning to the Edison companies, for although they had sole rights to the patent, the patent itself would expire in 1894 (Hammond 1941:184-186). In the long run, it would be in Edison's interest to merge with other companies, especially those with expertise in the AC technology that Edison lacked. Since Thomson-Houston had the American patent on three-phase technology, it was particularly attractive as a potential partner (Myers, personal communication 1992). Some of Edison's competitors, mindful of the cost of the patent battle, were also receptive to amalgamation.

All of this led to the merger of Edison General Electric and Thomson-Houston in 1892, as the General Electric Company (Hammond 1941:194). It is generally assumed that the specifics of the merger were masterminded by Charles A. Coffin of the Thomson-Houston Company, which then had its offices in Lynn, Massachusetts. The creation of General Electric led to greater efficiency in the production of electrical equipment. This was acknowledged even by those who thought the new company looked too much like a monopoly. And in many ways it was a monopoly; the only serious competition after the merger was Westinghouse, and even Westinghouse could not touch the burgeoning distribution franchises that made Edison/General Electric tops in the field.

The invaluable contribution of Thomson-Houston to the merger was expertise in alternating current technology. In the beginning, there was a period of basic classroom instruction, as Thomson-Houston personnel imparted their knowledge of alternating current to the Edison staff in Schenectady. Foremost among these newcomers was Charles Steinmetz, who established the law of hysteresis, which governed power loss in the magnetic circuit of electric motors. Steinmetz's formulae for dealing with alternations, cycles, and phases were a break-through in the understanding of AC power, and his addition to the staff gave General Electric an even greater competitive margin (Hammond 1941:199, 230; Hammond 1924).

Innovations began almost at once, and they were not limited to theory. Personnel from the old Thomson-Houston plant were soon relocated in Schenectady, working on new three-phase induction motors. Because these machines were self-starting, they were far better than the old single-phase AC machines and were able to compete with DC motors (Hammond 1941:209-210).

Westinghouse personnel also did work on new induction motors. Foremost among them was B.G. Lamme, who designed a new model in 1892 that would later be known as Type B. By 1895, Lamme had designed the so-called Type C motor, which was vast improvement over all earlier models. Type C was to all effects essentially the same as a modern electric motor (Cope 1936:8).

The development of the new AC motors was parallel to the development of longer AC transmission lines. The first of these longer lines used single-phase current at 133 cycles. The Stanley Company was one of the first to promote the polyphase system because they could more easily provide the lower frequencies that motors preferred.

The first long distance polyphase AC transmission line is believed to have been built between Housatonic and Great Barrington, Massachusetts, a distance of seven miles. In 1893, this line was strung on wooden poles and insulated with porcelain insulators and iron pins, both imported from Britain (Hammond 1941:218). Two other polyphase lines followed almost immediately, so close in fact that it is difficult to say which of the three was first. One was in Taftsville, Connecticut, and the other, in southern California (Hammond 1941:218). The latter, between the Mill Creek 1 powerhouse and Redlands, will be discussed in the section to follow.

By the early 1890s, it was clear that AC power had superseded DC in almost all areas of electrical generation (Hammond 1941:238). The last hold-outs for DC were the electric trolley lines, which had to use DC motors because they adjusted to differences in speed better than AC motors (Myers, personal communication 1992). Finally, in 1893, even this problem was surmounted with the invention of the rotary converter (or synchronous converter) that could convert AC to DC for trolley line use. From that point on, all electricity could be generated as alternating current, and everything could be placed onto a single system of electrical generation (Hammond 1941:230).

After years of confusing technological innovation, electrical generation and transmission entered a period of rapid standardization, based on what was found to be the best in a sea of inventions stretching over the previous 20 years. Incandescent lamps replaced arc lights for interior lighting, and alternating current replaced direct, with the exception of special functions. Transformers became the basis of electric transmission, which was stretched to greater and greater lengths. All this led to enormous changes in business. Induction motors and wiring systems replaced the elaborate shafting and belting that had once been standard in factories. This freed industry from the need to be near waterfalls and coal fields. Factories could now be situated with greater flexibility. As this occurred, lighting companies expanded their services to become power and light companies. And power and light companies proliferated across the nation.

The 1890s saw not only the phenomenal spread of power and light companies throughout the United States, but also the merger of local companies, many of which were based on old Edison or Thomson-Houston licenses. Wherever these mergers took place, the Edison name was generally preserved because it was already a household word. General Electric supplied many if not most of these amalgamated companies with all their equipment, reaching service agreements with almost 1500 power and light companies by 1894 (Hammond 1941:249,259).

By this time, electric power and light companies were fast becoming a considerable force in southern California, and were already mirroring trends that were becoming standard practice in the Northeast and the Midwest. In many ways, however, electrical systems in southern California began to progress along their own lines, drawing from and improving upon a foundation of technology established during the previous two decades of electrical innovation.

3. EARLY ELECTRICAL DEVELOPMENTS IN SOUTHERN CALIFORNIA

Overview, 1882-1892

The phenomenal development of electricity coincided with the equally phenomenal population growth of southern California. The Gold Rush of the late 1840s brought thousands of Euroamericans, Asians, and Central and South Americans to California, but most of the newcomers settled first in the Central Valley and the San Francisco Bay area. 8y 1850, the Census Bureau listed 93,000 people in the state; by 1870, there were 560,000; and by 1890, 1,213,000. Many of the later settlers moved to southern California, which experienced a particularly rapid growth during the land boom of the 1880s and 1890s. Los Angeles County alone grew from 15,309 people in 1870, to 33,381 people in 1880. By 1890, there was a three-fold increase to 101,454. This almost doubled again by 1900: 170,298.

Even though the population growth of what is now the San 8ernardino and Riverside area was considerably smaller during this period, the growth rates were proportional. In 1880, before Riverside County was formed, the area had a population of some 7786. This population trebled to 25,497 by 1890, and almost doubled again by 1900. By that point, Riverside County had been split off from San Bernardino (since 1893), with populations of 17,897 and 27,929, respectively.

More important to the commercial development of electricity was the growth of local cities. In 1870, Los Angeles had only 5000 inhabitants. By 1890, the number was 10 times that great, or 50,395. It doubled by 1900 to 102,479. Railroads were responsible for most of this growth. The Southern Pacific completed its first line into Los Angeles in 1876. The Santa Fe Railroad followed in 1885, further releasing thousands of laborers who sought residence and employment in the cities. Competition between these two lines fostered a price war in transcontinental transportation and brought many thousands of easterners to the area (Myers 1986:10).

The price war also brought on the so-called Land Boom of the late 1880s, as new communities sprang up almost overnight across the greater Los Angeles Basin. One of the areas most affected was San Bernardino County, east of Los Angeles. In the 1880 census, San 8ernardino was counted as a town (1673 people), but Redlands and Riverside were nothing more than precincts. By 1890, all three cities were on the map. By 1900, Redlands had almost 5000 people, San Bernardino had just over 6000, while Riverside tallied almost 8000. Many of the newcomers to these portions of southern California were familiar with the latest electrical innovations and had no intention of doing without them (Myers 1986:11).

As a result of the railroads and the people they brought in, there was relatively little lag between electrical developments in the Northeast, and their manifestation in southern California. The new electrical innovations came to southern California in three phases. The first was the Brush-type arc light system, powered by direct current. The second was the Edison combination of DC power and incandescent lamps; the third, alternating current.

The first arc street lights were installed in Los Angeles in 1882 by the Los Angeles Electric Company, which had a Brush franchise. The arc lights were placed on masts 150 feet tall at seven major intersections downtown. Three arc lights were placed on each mast, all powered by Brush dynamos (Myers 1986:12; Hinson 1956: Historical Notes).

In that same year, 1882, electricity first came to San Bernardino County when George Chaffey, developer of the Etiwanda Colony, placed a large arc light in the vicinity of his ranch house. Foreshadowing things to come, Chaffey's arc light was powered by a small generator set up on an irrigation canal near the colony (Myers 1991a:2).

By 1888, the Highgrove plant, built by Charles R. Lloyd three miles north of Riverside, was producing electricity and was possibly the first commercial hydroelectric plant in all of California (Myers 1986:20). Making use of a 40-foot drop in the Warm Creek Irrigation Canal, Highgrove had a 200-foot long redwood flume that brought water to the powerhouse. Water then went through an iron penstock pipe to a water turbine at the bottom of the drop. Shafts and leather belts then transferred power from the turbine to the electric generators in the building above the turbine. The DC generators created 300 horsepower, or about 75 kilowatts. The voltage was about 1000. From its first arc light in front of Wieck's Drug Store in Riverside in the spring of 1888, the system spread to provide electric arc lighting for Riverside and Colton, covering an area about 3 to 5 miles on the north and south sides of the powerhouse (Myers 1991a:2-4).

In 1888, Lloyd also built a small hydroelectric plant on Mill Street in San Bernardino. The plant was situated on the site of an earlier water-powered grist mill built on Warm Creek in 1851 by the first Mormon settlers (Hinson 1956:1-2). After the Highgrove plant was modernized and the Mill Street plant in San Bernardino was opened, the two facilities became the power source for the San Bernardino Electric Light Company (Hinson 1956:17).

In the late 1880s, a number of similar DC generating plants sprang up across southern California. In Visalia, a small steam plant powered arc street lights. The firm created to run this plant, the Visalia Gas and Electric Light Company, would soon fold, but others proved more long lasting. A small hydroelectric plant provided arc lights for the Ventura Land and Power Company. The DC power provided by this plant was transmitted five miles. The Santa Barbara Electric Light Company had two Thomson-Houston dynamos that powered arc street lights. The Pasadena Electric Light and Power Company provided arc street lights with a small steam plant (Myers 1986:14-17; Hinson 1956: Historical Notes, 1-2).

In 1890, the second and third waves of electrical innovation washed over southern California almost simultaneously. The second spurt came with the introduction of the Edison distribution system of direct current and incandescent lamps, which was installed in downtown Los Angeles. Variants of this system were already popular in the larger Eastern cities, but had never really been attractive in the West because the combination of direct current and incandescents could not cover great distances (Hinson 1956:2-3). In California, the Edison system had only limited application and was soon overshadowed by the more attractive features of alternating current.

The third wave, alternating current, also came in 1890. AC generators were installed in five different places that year: Santa Barbara, Highgrove, Visalia, Santa Ana, and Pasadena. Most of these were placed into existing DC plants that had formerly supplied arc lighting. Most of these AC generators powered the new incandescent lamps. The generators themselves were rather small, less than 100 kilowatts, had revolving armatures, and produced single-phase AC power at a high frequency (around 125-133 cycles) and 1100 volts (Hinson 1956:3-4).

Until around 1890, electrical developments in southern California were basically reactive, which was the case in most parts of the country outside of the Northeast and parts of the Midwest. Electrical systems were imported and installed, with little or no feed-back from the local environment. For southern California, this situation would change with the introduction of alternating current and the much longer distribution system that it promised to deliver. Here, the electrical situation switched very quickly from reaction to innovation with the combination of AC generation and hydraulic power.

Even by 1890, hydraulic power had a venerable tradition in California. The enormous range in elevation found throughout much of the state allowed the placement of grist mills and water-powered mining equipment along almost any mountain stream. As cities developed in the plains below, the water power provided by irrigation canals was also exploited. With this abundant natural resource, it was inevitable that water wheel technology would reach its peak in California.

The first water wheels in California had flat plates that served as paddles. These were known as "hurdy gurdy" wheels. By around 1870, hemispherical cups were first used in place of plates, and the new arrangement was soon called an impulse wheel.

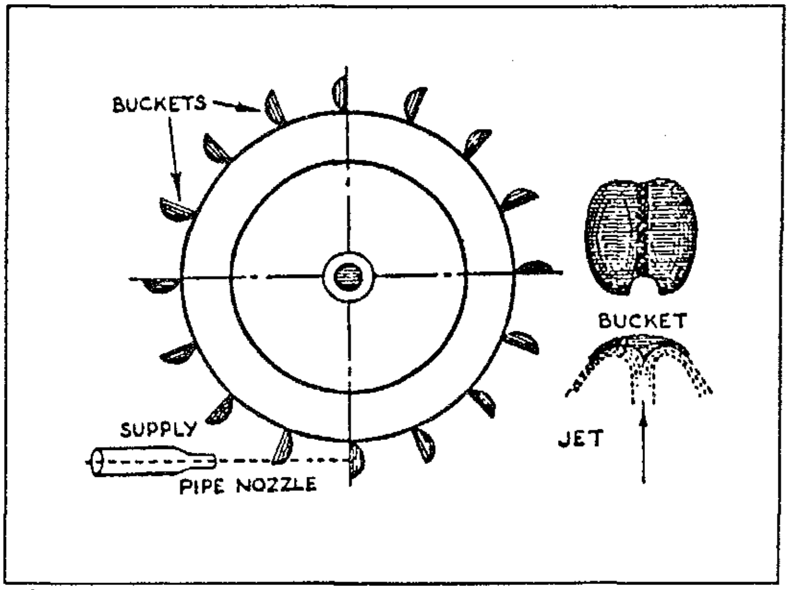


Figure 8. Principle of the Pelton Wheel (Allen 1958:532)

Initially, the goal was to get water to strike the center of the cups. By accident, Lester Pelton, a blacksmith by trade, discovered that the wheels moved faster when water struck one edge of the cups and exited the opposite side. From this, Pelton conceived the split bucket, where water could strike the edge of two buckets simultaneously. This invention was patented in October of 1880. Pelton's water wheels soon became a national standard. By the 1890s, his wheels had an estimated efficiency rating of at least 80 to 85 percent. This was brought about by an additional feature, which was the cut-away at the base of the double buckets. In 1889, Abner Doble improved upon the Pelton design by adding ellipsoidal or oval buckets (Allen 1958:532-533; Hay 1991:I:4-5; Figure 8).

The hydraulic developments of Pelton and Doble promised to mesh very well with the generation of AC electricity. What merged the two was the need for cheap fuel in southern California. Even with transcontinental railroads, coal proved to be too expensive to transport in great quantities. Even coal from the other side of the Pacific Rim was too expensive. Early steam plants in southern California were usually stoked with wood, which was itself a limited resource (Fowler 1923:30; Myers 1991b:47-49). By around 1910, California oil would fill much of the demand that coal could not supply, but before that time, hydroelectric power, the merging of hydraulic power and alternating current, was the promise of the future. As an example of its importance, by around 1900 hydro power was often referred to as "white coal."

The first AC hydroelectric plant with a long transmission line was that between Oregon City and Portland, a distance of 13 miles. Built in 1889 and placed in operation in the summer of 1890, this single-phase system had a potential of 4000 volts. Only step-down transformers were used in this system, to make the current usable for lighting in Portland (Fowler 1923:1; Rustebakke 1983:2).

Other single-phase AC systems were installed in other parts of the West by 1892. One of these was at the Telluride Mine in western Colorado, placed into operation in June 1891. This system had a single-phase AC generator that powered a synchronous motor at the other end of the 2.6-mile transmission line. Both machines were virtually identical, with one used as a generator and the other as a motor. Both were made by Westinghouse, with each rated at 100 horsepower. The generator produced 3000 volts and there were no transformers. The current was carried over two bare copper wires on poles and glass insulators (Myers 1990:18-20). Another source states that Telluride was placed into operation in June of 1892, but otherwise the basic information is the same (Fowler 1923:1).

Another early single-phase AC system was located at Bodie, in Mono County, California. Using Westinghouse equipment, the ore mill of the Standard Consolidating Mining Company was rigged with power from a water power source 12.5 miles away (Hay 1991:I:xx). Single-phase AC was selected over DC because the cost of the copper wiring would be less, but there were no transformers employed in this system because they were more expensive than the extra copper needed to make the AC line viable. The transmission line was completed by November 1892 with a capability of 3000 volts. Due to a delay in the arrival of the mill apparatus, however, the system was not energized until August or September of 1893 (Myers 1990:24-26). By that time, the technology employed at Telluride and Bodie was left far behind by electrical developments in southern California, where AC current and long distance transmission were pushed to new levels by the demands of a burgeoning population.

The Pomona Plant, 1891-1892

The first long-distance, high-voltage transmission line in the United States is believed by many to have been the so-called Pomona Plant, also known as the San Antonio Plant. The single-phase 1100 volt current created by the generator was stepped up to 10,000 volts for transmission by a bank of transformers (Cope 1936:11). It is thought that this was the first time that current had been stepped up for transmission.

The Pomona Plant had its beginning with Dr. Cyrus G. Baldwin, who was made president of Pomona College in 1890 (Myers 1986:23). Baldwin often explored the San Gabriel Mountains north of Pomona and was also familiar with the small hydroelectric plant that served Ventura. He thought that the San Antonio Creek waterfall would be a good site for hydroelectric power generation. Baldwin soon discovered that the water of San Antonio Creek belonged to the Pomona Water and Irrigation Company and that he had to purchase the land and rights to use the water. To that end, Baldwin organized his own company in May 1891. This became known as the San Antonio Light and Power Company (Hinson 1956:4-5).

Construction of the water conduit began almost immediately and entailed the excavation of a 1300-foot long tunnel that was initially lined with redwood boards. When these leaked, the tunnel had to be cleaned out and lined with concrete (Myers 1986:26). The head of the Pomona plant was about 400 feet. The plant itself was equipped with four Pelton wheels, each with a 34-inch diameter (Long Distance Electric Power Transmission 1892:76-77).

The design of the electric generators and the entire electrical system was far beyond Baldwin's capabilities, and he acquired the services of a relatively young electrical engineer, Almerian William Decker, to draw up the plans and specifications for the new plant. Decker's plans called for a three-phase alternating current generator, one of the first and the largest that had been conceived to that point. The design also called for a voltage step-up, step-down transmission system, also one of the first of its kind.

Decker was well qualified to choose among the different mechanical options available because he had spent his life exploring varied aspects of electricity. Born in Ohio in 1852 of New England stock, Decker had experimented with machinery and electroplating. One of his early jobs was with the Union Metropolitan Telegraph of Cleveland. Soon he was working more intensively in electricity for the Charles F. Brush Company. By this time, he had already damaged his respiratory system with electroplating experiments and was told to move west for drier air. This he did in early 1891; by the end of that year, he had settled in Los Angeles County, where he first met Dr. Baldwin (Low 1903:96; Hinson 1956:5).

Decker already had a number of patents, one for an elevator safety device, another dealing with electroplating, and still another for an electric marking device used in the manufacture of wooden rulers (Myers 1986:24). He had also conducted experiments with the new AC generators while in the employ of the Brush Company. Decker was thus familiar with electricity and the new AC systems in a way that most local engineers were not (Hinson 1956:5).

On a trip back East, Dr. Baldwin took Decker's plans to the Westinghouse Manufacturing Company, which declared the three-phase generator impractical (Myers 1986:27). At this time, Westinghouse engineers were perfecting their two-phase AC system (Hay 1991:I:19). Baldwin next took the plans to William Stanley in Massachusetts. Stanley offered suggestions of his own, and it was probably at this point that the three-phase idea was dropped in favor of the more traditional single-phase. Stanley advised Baldwin to see the Thomson-Houston Company in Lynn, Massachusetts. If Thomson-Houston would not produce the generator, then Stanley promised to do it himself (Hinson 1956:5).

Initially, the Thomson-Houston people were not interested, but were eventually persuaded to give it a try since Stanley had agreed to do it otherwise. Thomson-Houston gave Baldwin a figure for this work, which Baldwin took back with him to California. Two weeks later, Westinghouse also submitted a quote. Back in California, Decker chose the Westinghouse option (Hinson 1956:6).

Westinghouse outfitted four single-phase AC generators for the Pomona plant, each rated at 200 horsepower. The two exciters that were to catalyze them were rated at 20 horsepower each (Long Distance Electric Power Transmission 1892:76-77). The generators were direct connected to the water wheels, rather than belted, and operated at 600 revolutions per minute (rpm), the estimated speed of the water wheels. This was considered rather slow for a generator of that time. Each generator had 12 poles or electromagnets, which, combined with the 600 rpm, gave a total of 7200 electrical alternations per minute. This translated to 60 cycles. The generators produced a total of 1100 volts (Hinson 1956:7; Myers, personal communication 1992).

An integral part of Decker's plan called for the use of transformers to step up the voltage for long distance transmission, something that had not really been tried commercially before. For this task, Decker had 20 oil-filled transformers, each rated at 100 light or 6 kilowatts. These were considered the largest at that time, adequate to match the generator capacity of 2000 light or 120 kilowatts. Each transformer was wound for 1150-volt primary and 517-volt secondary; the primaries were connected in parallel to the 1100-volt generators. Each transformer was fused separately. At the suggestion of William Stanley, all secondaries were connected in series, which then produced a total of 10,340 volts (Hinson 1956:7-8). Multiple transformers were needed in this way to do the voltage step-up because transformer technology was still rather primitive (Myers, personal communication 1992). Decker's original plans had called for a 5000-volt generator and larger transformers in parallel, wound for 5000 volts to 10,000 volts, but Westinghouse did not think that such things could be built (Hinson 1956:8).

The 10,000-volt current was carried on two No. 7 bare copper wires. The transmission line first went seven miles down the canyon, and then 15 miles to Pomona (Long Distance Electric Power Transmission 1892:76-77) The transmission line and the voltage were very rough examples of Decker's rule of thumb, which called for 1000 volts of pressure for every mile of transmission (Myers 1986:24).

At Pomona, the high-voltage current was stepped down to 1100 volts by 19 transformers placed in series parallel. The local voltage was controlled by a hand-operated "Stillwell" voltage regulator (Hinson 1956:8). This system began operation in either November (Myers 1986:26, 1991a:50) or December of 1892 (Fowler 1923:1).

Another line was soon added to the system, a 29-mile transmission line to San Bernardino. Voltage was stepped down at the end of this line with 18 transformers placed in series parallel (Baldwin 1899:5; Hinson 1956:8). This line must have been added almost immediately, since it was mentioned as early as 1892 (Long Distance Electric Power Transmission 1892:76-77).

The Pomona plant did not last even 10 years, before it was destroyed by flood in 1900 (Myers, personal communication 1992). The San Antonio Light and Power Company turned over the ruined facility and its assets to the Sierra Power Company, which was incorporated in 1900. Sierra built a new plant in the canyon 0.5 mile farther downstream. The plant was appropriately named "Sierra," and was placed in operation in February 1901. At that time, the Pomona plant site was permanently abandoned (Hinson 1956:26).

Although no longer extant, the Pomona plant claimed a number of firsts in the development of electrical power generation, both in southern California and the nation at large. It is believed to be the first plant to step up voltage for long-distance transmission (Hinson 1956:9). The transmission voltage, commonly rated at 10,000 volts, was the highest used up to that time (Myers 1986:25). The Pomona plant was also the first to have oil-filled transformers (Hinson 1956:8 footnote). In the way the transformers were used, it has been claimed that Decker (with Stanley's assistance) was even responsible for the modern application of transformers (Fryer 1980:55). He would perfect this use of transformers with his work at the Mill Creek plant, which was under construction even before the Pomona plant went on line.

The Mill Creek Plant, 1892-1896

The Mill Creek plant, built between 1892 and 1893, represented another milestone in the development of electrical technology in southern California. Coming soon after the Pomona plant, the Mill Creek powerhouse borrowed many of the innovative features of its predecessor, and took these yet further. The connection between the two plants was more than theoretical; Almerian Decker was working on the designs of the Mill Creek plant before the Pomona facility was even put on line. At Mill Creek, he was determined to implement the three-phase AC system that had eluded him at Pomona. For Decker, this was a race against time, since he was already in declining health and did not have long to live.

In the planning of Mill Creek, Decker worked for the community of Redlands at the eastern end of the San Bernardino Valley. Redlands was one of the many communities established during the Land Boom of the 1880s, but it had the distinction of being one of the most successful. Begun around 1887, Redlands was organized as a town for transplanted Northeasterners. By the early 1890s, it had a population of about 4000, most of whom were active and well-educated (Low 1903:10). By 1890, it was already a town scandal that there was no local electricity, save for a few private plants (Hammond 1941:231).

By the time electricity was seriously considered as a motive power, it was feasible for the community to turn to the hydraulic power provided by Mill Creek. Coal was too expensive to provide a serious option, and oil was not yet available in sufficient supply. Also, Mill Creek water had been utilized in the Redlands area since irrigation water was first pulled out of Mill Creek by the mission fathers in the early 1800s (Hinson 1956). That water was just as important later to the orange growers of the 1890s.

To supply hydroelectric power, the Redlands Electric Light and Power Company was conceived in January 1892 by Henry Fisher, George H. Crafts, George B. Ellis, F.G. Ferand, and H.H. Sinclair. The company was incorporated in the spring, and overtures were made almost immediately to Almerian Decker, who was then working on the Pomona plant. By June 1892, Decker was employed as the chief electrical engineer for the Mill Creek project (Low 1903:10). By this time, the three men who were the driving force for the new plant were Sinclair, Henry Fisher, and Almerian Decker, who were sometimes referred to collectively as the "Redlands Group" (Trott 1919:16).

Sinclair and Fisher were both powerful voices in the community, even though they had only been in the area for a few years. Henry Fisher had made his money in Pennsylvania oil before moving to Redlands in the late 1880s. He quickly established local business interests that extended to both Pasadena and Los Angeles. Fisher became one of the pillars of the Redlands Electric Light and Power Company. His son, J.H. Fisher, would later be a company director (Secord 1985:8:10).

Henry H. Sinclair, perhaps the prime business force behind Redlands Electric Light and Power Company, was born in Brooklyn in 1858. After a stint as a sailor, he took science courses at Cornell University prior to operating a shipping business in New York. Sinclair moved to Redlands in 1887, and bought a 30-acre fruit ranch. Active in civic affairs, Sinclair was on the first board of trustees for Redlands University. He also had a number of interests in local water companies (Secord 1985:8:9).

The main impetus for the Mill Creek plant, aside from Redland's lighting needs, was the demand for refrigeration. Specifically, the Union Ice Company of Mentone had need for a 150-horsepower motor to create the ice needed for shipping oranges. To that end, the Union Ice Company contracted with Redlands Electric Light and Power for a 150-horsepower load. This contract was the initial financial basis for the Mill Creek plant (Hinson 1956:10-11; Low 1903:11). Other uses for this electricity were also anticipated, such as the operation of future street cars in Redlands and other electric rail lines that would connect Redlands with Riverside and San Bernardino (Low 1903:10).

Because a large motor was involved at the planning stage, it was clear to Decker that the Mill Creek system would be better with three-phase, not single-phase, AC power. In fact, Decker's plans called for a three-phase transmission system with a rated capacity of 400 kilowatts (Low 1903:11). In 1891, the first long-distance three-phase system in the world was installed in Germany from Lauffen to Frankfort, a distance of 112 miles. This system operated with a transmission line carrying 25,000 volts (Hughes 1983:133-135; Rustebakke 1983:2). Decker knew of the German three-phase system and believed it would work for Redlands (Hinson 1956:11).

As discussed earlier, electrical motors operate much better with three-phase alternating current than with single-phase. Single-phase motors could not be self-started, but rather had to be started at the same time as the generator itself. For this reason, such motors were called synchronous motors. A three-phase or polyphase machine had the advantage of being able to start independently of the generator. Three-phase electricity was also capable of running both motors and lights.

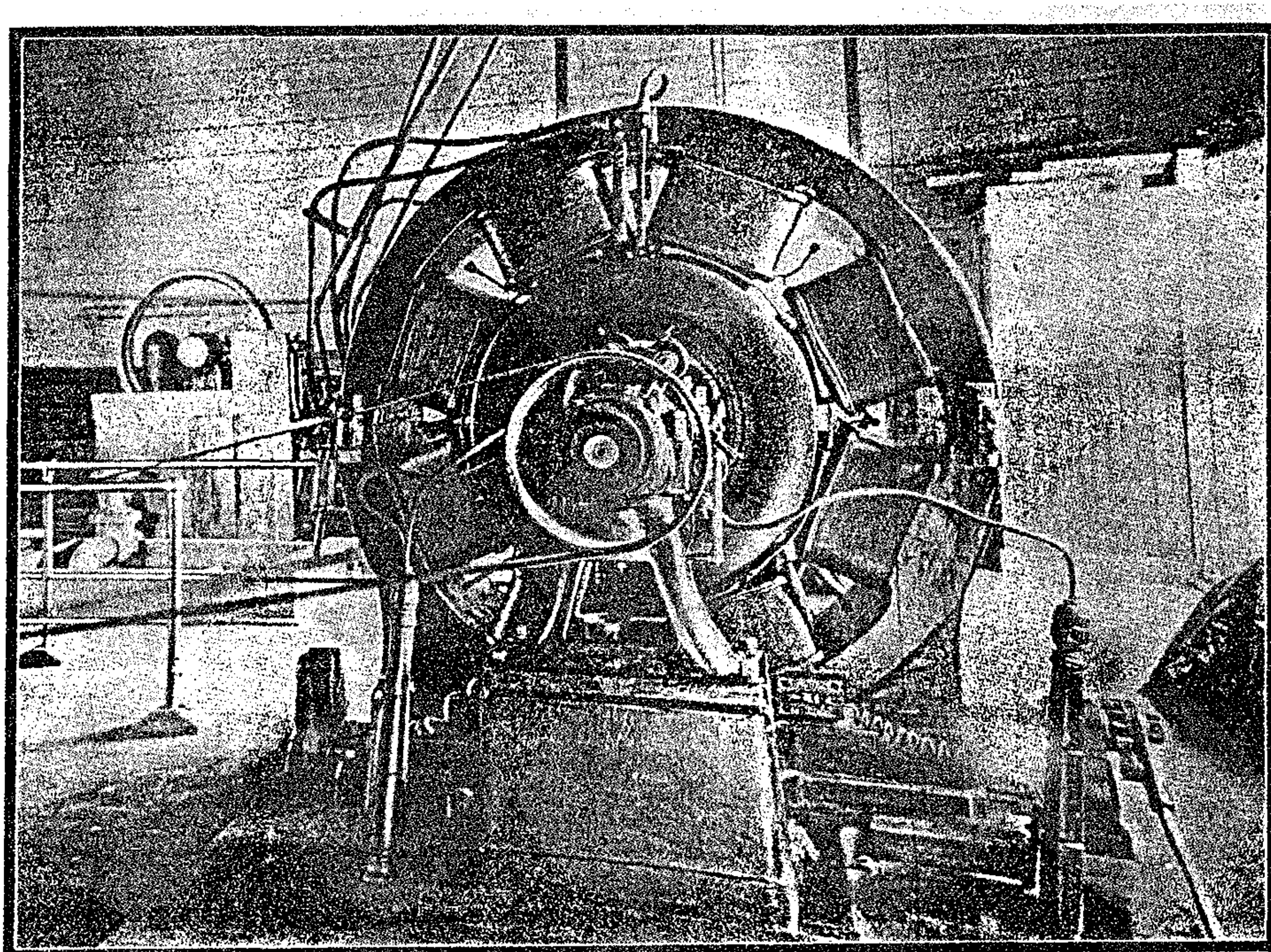
In generating three-phase electricity, each of the three wires wrapped around the generator coil picks up a different impulse in the wave cycle created by the electromagnets. For this reason, each of the three impulses has to be transported on its own wire, which is still true today. These matters and others concerned Decker as he worked up the "Plans and Specifications" for the Mill Creek plant. Before the end of 1892, these plans went out for bid.

By this time, Thomson-Houston had merged with Edison, and a set of the plans went to the new General Electric Company, which was taking advantage of its new Thomson-Houston personnel to expand into AC generation. Plans were also sent to Westinghouse, to Siemens and Halske Electric Company in Germany, and to the Electrical Engineering Company of San Francisco (Hinson 1956:12).

General Electric won the Redlands contract on the strength of its new "TY" three-phase AC generator, a 250-kilowatt machine, with an output of 2400 volts (Myers 1986:27; Hammond 1941:232). General Electric agreed to provide two 250 kw generators with 10 poles and an operating speed of 600 rpm, or 6000 alternations per minute. In modern terms, this would be 50 cycles. The generators were designed to create current of 2500 volts (Hinson 1956:12-13). The three-phase induction motor required for the Union Ice Company is believed to have been only the third such induction motor installed by the Thomson-Houston people at General Electric (Hammond 1941:210).

An interesting feature of both the Mill Creek generators and the Union Ice Company motor, was the placement of the electromagnets on the stator and the windings on the rotor (Figure 9). Although this arrangement had been standard on DC generators, it was something of an experimental design on AC models. Although this arrangement was later used in the big Niagara Falls plant that opened in 1895 (Hay 1991:I:24-25), it did not become popular. In fact, it was a feature rather unique to AC generators and motors of the early and middle 1890s (Myers, personal communication 1992).

Figure 9. Three-Phase Synchronous Motor, 1903
(Fryer 1980)



THE FAMOUS PIONEER THREE PHASE SYNCHRONOUS MOTOR WHICH RUNS THE PLANT OF THE UNION ICE COMPANY AT REDLANDS.

Due to Decker's illness, the two polyphase generators were installed under the supervision of Fred Barber, a General Electric sales agent and field engineer (Hammond 1941:232; Myers, personal communication 1992). Original plans called for the generators to be belted to the Pelton water wheels, but when they were installed they were direct-connected, with a three-bearing shaft to hold the wheel and generator in place. Each generator was excited by two 7.5 kw, 125v, compound-wound exciters. These were driven by their own independent Pelton wheels, which operated at a speed of 1600 revolutions per minute (Low 1903:11-12).

General Electric followed Decker's plans without question, except in the matter of trying to make the two generators work in parallel. The chief engineer of General Electric communicated to the board of directors of Redlands Electric Light and Power Company that there was no reliable way to achieve this synchronicity. Finally, Dr. Louis Bell of General Electric made an acoustic device that came to be known as the "growler" (Pearson 1912c:14). Based on Decker's original specifications, the growler had two diaphragms of sheet metal, each connected to a generator. The diaphragms were then connected by a brass cylinder with an opening in the middle. In theory, a listener should have been able to tell when the two generators were vibrating in harmony. In fact, the growler just created an indecipherable din; no reliable aural method was ever found for synchronizing generators (Hammond 1941:232-233; Low 1903:12). General Electric did, however, eventually develop a visual method of synchronizing generators using flashing lights (Myers, personal communication 1992).

Construction of the plant itself was directed by Albert C. Jewett (Hammond 1941:232). The water conduit system provided a head of 295 feet, with an estimated power potential of 359 kw. This potential was augmented in later renovations (Low 1903:11-12). Daily supervision of the plant construction was conducted by O.H. Ensign, who had worked under Dr. Louis Bell at Schenectady (Pearson 1912d:15); Decker was now too sick to visit the plant on a regular basis. At one point, Decker had four men carry him on a cot to the Mill Creek plant so that he could check the installation of the machinery (Pearson 1912c:13). Decker died on 3 August 1893 (Myers 1986:29), at least a month before the powerhouse was ready to go on line.

According to some sources, the Mill Creek plant went into operation in September 1893 (Hinson 1956: Historical Notes, 10); according to others, it was in November (Hammond 1941:232-3; Pearson 1912c:14). Either way, it was considered by many to be the first three-phase generator to be put into "commercial" (non-experimental) service in the United States (Hinson 1956: Historical Notes, 13; Rustebakke 1983:2).

Power from this plant was transmitted to the Union Ice Company in Mentone, 4.5 miles away, and then continued in the same direction for a total of eight miles to Redlands. The transmission line consisted of two three-phase circuits. Each of the six wires was a No. 6 B & S gauge, bare copper wire. The wires were strung on poles; the insulators were "common deep-groove, double-petticoat, 2200-volt glass insulators" (Low 1903:11). Initially, the pressure on the line was 2300 volts. The ice plant motor also operated at this voltage, so there was no need for a transformer in Mentone. Only in Redlands was the power stepped down for the electric lights (Low 1903:11).

To support both motors and lights, Redlands Electric Light and Power Company ran the Mill Creek plant on a frequency of 50 cycles. From this beginning, 50 cycles became the standard for southern California in later years, even though the national standard was developing into 60 cycles (Rustebakke 1983:2). Only years later, when power companies became interconnected, would this difference become a problem.

In 1896, a new transmission line was strung from Redlands to Colton and Riverside, primarily for municipal electricity and agricultural pumping. At this point, the Mill Creek transmission line voltage was jacked up to 10,000 volts by means of three 100 kw Wagner transformers (Fowler 1923:1-2; Lighthipe 1899:3; Low 1903; Myers, personal communication 1992). It was at this point that porcelain insulators were first used on the line, but it would appear that these were later replaced by special 10,000-volt insulators known as the "Santa Ana type glass insulator" (Perrine 1903:55). These glass insulators became known as the "Santa Ana" type, and were different from the later porcelain insulators known as the "Redlands" type, which was used with the Santa Ana River powerhouses (Myers, personal communication 1992). A more detailed discussion of these insulators is included in the section dealing with the first Santa Ana plant.

To create the extra energy needed for the system, the Mill Creek water conduit was extended another 3000 feet, which increased the head by 86 feet for a total static head of 510 feet. The total length of the new conduit was 10,250 feet, most of which was riveted steel pipeline, 30 inches in diameter. Also, new Pelton wheels of a more modern design were installed (Low 1903). An AC steam generator had already been added to the powerhouse to supplement the hydro power during periods of low water. The new system worked so well that the original generators remained on line until 1934 (Myers 1986:31).

The Mill Creek plant, now known as Mill Creek No. 1, had an immense impact on the development of electricity in southern California, as well as the rest of the nation. The success of the polyphase AC system at Mill Creek led to the complete abandonment of single-phase AC technology at General Electric (Hammond

1941:231). Soon, three-phase current, backed by General Electric, edged out the two-phase technology championed by Westinghouse to become the basis of modern electrical generation (Myers 1991b:25).

Locally, the success of Mill Creek popularized the use of electric motors in the operation of irrigation pumps. Partly for this reason, electrification came to the rural areas of southern California, and in particular to the Inland Empire, long before it was available to most other rural areas (Hinson 1956:13; Myers 1991b:29).

The impact on the utility industry was even greater. The Redlands Electric Light and Power Company and the people who ran it were noticed and emulated as far away as Los Angeles. By the time that Santa Ana River No. 1 was under construction, the Redlands company and one of the fastest growing electrical companies in Los Angeles were on the verge of a merger, and the personnel of Redlands Power and Light would help form what would later grow into one of the largest utility companies in the West, the Southern California Edison Company (Hammond 1941:231). The Redlands side of this consolidation has been presented; the other side begins with the development of the West Side Lighting Company of Los Angeles.

West Side Lighting Company and the California Edison System, 1888-1909

The Los Angeles Electric Company had been providing DC power to parts of downtown Los Angeles since 1882, but it was not the progenitor of the enormous Southern California Edison system that is in place today. This system had its beginnings with a much smaller firm, usually identified as the West Side Lighting Company.

West Side Lighting had its beginnings in 1888, with Walter S. Wright of Pasadena and George Peck, who owned a small, 50-horsepower electric light plant in San Pedro. After municipal officials canceled an important light contract, Wright and Peck closed the operation in San Pedro and took the 50 horsepower generator with them to Los Angeles (Pearson 1912:4). Wright and Peck were awarded an electrical franchise from the Los Angeles County supervisors, but were less successful with city officials. For this reason, their first plant and center of operations were located on the west side of Los Angeles, as the name suggested (Pearson 1912:4-5). Sources differ as to when the firm first became known as the West Side Lighting Company. One implied that the name West Side was in use as early as 1895 (Pearson 1912:4-5), while another claims that the firm was first known as the Walter S. Wright Electric Company (Trott 1919:15-16). The latter seems more likely.

Wright and Peck's first powerhouse, a steam plant, was located on 22nd Street, just west of Hoover Street. The plant went into operation in the fall of 1895 and provided DC and AC power to its customers with one arc light generator and a 50 kw three-phase generator (Hinson 1956:15-16). Officially, the power lines that left this plant could only service the county, but customers in the city sometimes built their own transmission lines to join the company's lines at the municipal boundary (Pearson 1912:4-5).

The opportunity to provide more service to Los Angeles was seized in early 1896, when Walter Wright bought the so-called "Scott Franchise" (Hinson 1956:15-16). One of the few city electrical franchises had been given to a Mr. Scott; unable to finance the venture, he finally sold his franchise to Wright for 100 dollars. The only drawback was that the franchise had a time clause: Los Angeles city hall had to be lit for free, and this had to be done by the evening of 24 April 1896. According to one account, Wright's company had five days to string a line to city hall after the franchise purchase was made legal (Pearson 1912a:5).

The installation of this line took all of Wright's eight field personnel and the office staff, too. The line was finally activated at 4:45 p.m. on 24 April (Pearson 1912a:5). When the city hall was illuminated, it was reported that the field chief led the crew and staff in a rendition of the Doxology (Pearson 1912b:7-8). By at least two accounts, it was the lighting of city hall that led to the creation of the West Side Lighting Company (Hinson 1956:16; Trott 1919:15-16).

By the summer of 1896, West Side Lighting had all the work it could handle. The company bought the powerhouse and equipment of the old Second Street Cable Railroad, which had been abandoned for two years. The powerhouse was refurbished and operating by fall. Soon this plant was known as "Los Angeles No. 1" (Hinson 1956:16; Pearson 1912b:7-8; Dennis 1913:3).

When West Side started to move into the lucrative downtown market, it ran into more problems. Due to the number of power poles and telephone poles throughout downtown, the city decided not to permit any more overhead lines. West Side then looked into using the Edison system of underground lines. What they lacked were rights to the Edison patent, then held by the Los Angeles Edison Electric Company, which had incorporated in 1894 and floundered ever since (Hinson 1956:19). In December 1897, West Side Lighting merged with the Los Angeles Edison Electric Company for the purpose of getting its license, the General Electric franchise, and use of the Edison name. The merger was christened the Edison Electric Company of Los Angeles (Myers 1991b:87; Hinson 1956:19-20). The old board of directors of the West Side Lighting Company was preserved intact, and others were added. It was at this time that John B. Miller became a member of the board. He would later become an important figure in the development of the new company (Low 1903:16).

By the spring of 1898, a new substation was begun near Fourth Street and Main to house the generators supplying energy to the three-wire Edison underground system that would provide DC power to downtown customers. The Edison tubes were laid on both sides of all the major downtown streets (Hinson 1956:19-20). To power this DC system, three-phase AC power from the Second Street steam plant was transmitted to the Fourth and Main Street substation, where it was converted to DC power. This is believed to be the first Edison DC underground system installed in the American Southwest (Hinson 1956:20), and it was already a rather archaic system that was soon embedded in a rapidly-expanding network of alternating current.

When West Side Lighting merged with the Los Angeles Edison Electric Company to form the Edison Electric Company of Los Angeles in 1897, it precipitated a series of mergers and reorganizations that continued until the creation of the present Southern California Edison Company in 1909. Because the Santa Ana River powerhouses were built during this period of rapid name change, the company will often be identified by its generic name, Edison. Despite the name changes, Edison remained essentially the same company with a continuity of personnel throughout this period.

The phenomenal growth of the Edison company led to a search for new power sources and the acquisition of other companies (Secord 1985:8:5). The Santa Ana River system was developed, and the Redlands Electric Light and Power Company was absorbed (Pearson 1912:3). The subsidiary company responsible for initial construction work at Santa Ana River No. 1, the Southern California Power Company, was formally integrated into the system in 1902.

With the addition of the Southern California Power Company in 1902, the hybrid firm was reorganized as the Edison Electric Company. This company lasted until 1909, during which time, mergers and other acquisitions continued. On 6 July 1909, the Edison Electric company was reorganized as the Southern California Edison Company (Hinson 1956:42), the name by which it is known today. In 1917, Southern California Edison consolidated with the Pacific Light and Power Company, an action that merged the two largest electrical companies in southern California (Hinson 1956:47-48). In that same year, Southern California Edison also absorbed the Mentone Power Company, which had constructed Santa Ana River No. 3. This brought the entire Santa Ana River system under the control of Southern California Edison, where it has remained to this day.

The genealogy of the Southern California Edison Company is presented below in Table 1 (Myers 1991b:403). The electrical companies that were pertinent to the development of the Santa Ana system are also listed. The Santa Ana system, however, was not just incidental to the development of the Edison network. Santa Ana River Powerhouse No. 1 was a critical factor in the development of the Edison Electric Company of Los Angeles.

Table 1. Southern California Edison Corporate Genealogy

Walter S. Wright Electric Company
1888-1896

West Side Lighting Company
1896-1897

Los Angeles Edison Electric Company
1894-1897

Edison Electric Company of Los Angeles
1897-1902

Redlands Electric Light and Power Company
1892-1901 (Research Materials 1985, Untitled Document)

Southern California Power Company
1896/1897-1898 (informal Edison subsidiary)
1898-1902 (wholly owned subsidiary of Edison)
1902 (absorbed by Edison Electric)

The Edison Electric Company
1902-1909

Southern California Edison Company
1909-present

Mentone Power Company
1900-1903
1903-1917 (wholly owned subsidiary of Pacific Power and Light Company)
1917 (absorbed by Southern California Edison)

4. DEVELOPMENT OF SANTA ANA RIVER NO. 1

The alterations to the Mill Creek plant in 1896 advanced the electrical industry to the stage which made possible the design and operation of Santa Ana River No. 1 powerhouse. Other regional developments occurred in the years between Mill Creek and 1899, when SAR 1 went on line, but these in no way overshadowed the achievement of the Santa Ana plant. The Sacramento hydroelectric project, completed in 1895, had four General Electric generators, each producing 750 kw and producing three-phase alternating current; the transmission line was only 25 miles and only carried 11,000 volts (Hammond 1941:250). The Bakersfield project, completed in 1896, with a 14-mile transmission line from the Kern River to Bakersfield, also had a 11,000 volt line (Hammond 1941:251). The Azusa hydro plant, built by the San Gabriel Electric Company and up for commercial operation in 1898, generated 1200 kw at two-phase, which was then transformed to three-phase for transmission to Los Angeles, 23 miles away; the pressure on this line was 15,000 volts (Hinson 1956:20).

Much more significant was the Provo plant in Provo Canyon, Utah. Planned after SAR 1, Provo was put on line a few months before the Santa Ana plant. Even though the Provo-Mercur transmission line carried a pressure of 40,000 volts, the distance covered was only about 32 miles (Bly 1898:169-170; Myers, personal communication 1992). The Santa Ana plant, with a transmission line 83 miles long and a pressure of 33,000 volts, is generally considered the next milestone after Mill Creek.

Other developments in the Santa Ana River Canyon contributed to the hydraulic system of SAR 1. The water conduit work on this and the other canyon powerhouses was largely foreshadowed by the work of the Bear Valley Irrigation Company. Many of the techniques and materials used in the canals and flumes of the powerhouse were worked out earlier during the construction of the Santa Ana Canal, built in the early 1890s.

The Santa Ana Canal, 1892-1894

The Santa Ana River Canyon was not tapped for water use quite as early as Mill Creek Canyon, but, unlike Mill Creek, it was found to be the conduit to a large mountain valley deep in the San Bernardino Mountains. The lumber industry of the first Mormon settlers, and Holcomb's Gold Strike in the late 1850s, brought the first permanent Euroamerican settlement to Bear Valley (Foster et al. 1989:7). From then to about the 1910s, the Santa Ana River Canyon was the most direct route into Bear Valley from San Bernardino and Redlands (Hatheway 1987).

Bear Valley was recognized as a good location for a reservoir as early as 1880. Responding to the increased demand for irrigation water in the San Bernardino Valley, the Bear Valley Company built the first reservoir dam in 1883-1884. It was a single-arch construction made of the local granite, located in the 75-foot wide gorge that drains Bear Valley. Supplies were transported to the dam site over the Cajon Pass and up Holcomb Valley, rather than through the much more direct Santa Ana Canyon that was still too rough for most wagons (Hall 1888:179-188; Hatheway 1987:12).

Even though the Bear Valley reservoir was created to impound irrigation water, that water had to flow all the way down the Santa Ana Canyon before it could be turned into irrigation channels like the South Fork Ditch, located at the canyon's mouth. As a result, much water was lost to seepage and evaporation (Hall 1888:183). One of the incentives for the Santa Ana Canal was a desire to take irrigation water from higher up in the canyon.

To do this, the Bear Valley Irrigation Company was formed around 1890 (Hall 1895). Its primary objective was to provide irrigation water for some 45,000 acres in northern San Jacinto valley, located at elevations between 2040 and 1350 feet AMSL, sloping south from the San Timoteo Hills. The canal the company envisioned had to work around the limitations of the "Moreno Tunnel," located at an elevation of 2050 feet AMSL. This tunnel, dug through the San Timoteo Hills around 1890, was the controlling point of delivery; the elevation of the canal intake had to be higher than the Moreno Tunnel (Hall 1895:61-62).

Work began on the Santa Ana Canal, segments of which were later known as the Bear Valley Highline and the Highline Canal, between the Santa Ana River and the Moreno Tunnel in December 1892. Work was completed by August 1894. The construction progressed slowly due to the poor capital arrangements made by the Bear Valley Irrigation Company. In fact, the company went into receivership in December 1893 and was still seeking a buyer when the canal was completed (Hall 1895:66-68).

The intake of the Santa Ana Canal was located along the Santa Ana River at 2320 feet AMSL, more than two miles upstream from the mouth of the canyon. This would later be the location of Santa Ana River Powerhouse No. 2. From this point, the distance from intake to the Moreno Tunnel was 12 miles as the crow flies and some 42 miles following the contour. The hydraulic gradient was a little less than 10 feet per mile (Hall 1895:63-64, 76-77).

Initially, an intake farther upstream was considered, at an elevation of 3800 feet AMSL, putting the canal headworks just above the present intake of Santa Ana River No. 1. This option was not chosen due to the greater expense of such a canal, and the tight construction schedule the company was supposed to meet (Hall 1895:72-73).

The Santa Ana Canal was divided into divisions and sections that were numbered from the headworks to the Moreno Tunnel; Division 1, for example, was the segment from the intake to Mill Creek. Canal structures and substructures (e.g., trestle supports) were also numbered (Hall 1895:64-65).

The basic plan of the canal was to minimize the distance and the curves by tunneling the mountain spurs and spanning the canyons (Hall 1895:76-77). In Division 1, there were nine spurs that were shortened by tunnels through the rock and three canyons crossed by pressure pipes. In addition, there was one walled canal, and eight masonry walled structures such as sandboxes, junction bays, and outlets (Hall 1895:77).

Most of the distance was covered by tunnels. In Division 1, two of the tunnels were particularly long, about 1500 feet (Hall 1895:75, 88-92). During tunnel construction, the company engineers had to be very specific about the amount of dynamite used in order to keep the contractor from "blowing the hill to pieces" to make the work go faster. Where the walls and roofs of the tunnels remained solid, the company did not feel it was necessary to add concrete lining, but the first tunnel, adjacent to the intake, encountered soft pockets in the rock and was lined with concrete (Hall 1895:84-88).

Where tunnels were not required, flumes were used to carry water along the canyon wall. As a rule, the company tried to build flumes along the canyon side, with curves resting on solid benches whenever possible to avoid post and trestle work (Hall 1895:74-75). Whether on benches or trestles, the flumes were believed unique in their design and were generally identified as "stave and binder combination" flumes (Hall 1895:98-100). The wooden staves were bound and secured in a rounded-bottom, straight-sided form, held in place by iron and steel ribs and binding rods. Wooden yokes or ties were used across the top of the flume to hold the construction in place. The edges of the bottom staves were cut to fit each other and form a water-tight seal (Hall 1895:99-100). Where flume sills did not rest on rock or earth, flumes were supported on trusses or timber piers with masonry footings (Hall 1895:77).

The inside width of the flumes was 5.5 feet, and the depth below the top of the sideboards was 5.5 feet. They were designed to carry a 5-foot depth of water. When the canal was constructed, an oval bottom was considered the most efficient shape for a flume, but the experience obtained from the Santa Ana Canal suggested that an oval shape had no particular advantage over a semi-circular bottom in the case of small canals like the Santa Ana (Hall 1895:101).

In Division 1, three side canyons had to be spanned (Hall 1895:63-64). The first of these, Warm Springs, was later spanned by the conduit system associated with Santa Ana River Powerhouse

No. 3. For the Santa Ana Canal, these side canyons were spanned with inverted siphons, which were pressure pipes that dipped down with the canyon and relied on pressure to force the water back up on the other side. The Warm Springs pressure pipe was 551 feet long, and supported on trestles (Hall 1895:118).

The pressure pipes were made of redwood staves held in place with round steel rods. The end joints of these staves were closed with metal tongues that fit into the next stave. All of this was part of the Allen patent for a stave pipe; the Excelsior Wooden Pipe Company, a California firm, held the patent and manufactured these pressure pipes (Hall 1895:112).

The decision was made to use wood rather than metal for the pressure pipes because wood was cheaper and less affected by temperature change. The wooden pipes were not coated with coal tar or asphalt because it was thought to be unnecessary and because the wood was not dry enough to coat (Hall 1895:115).

The most ingenious portion of the Santa Ana Canal was generally considered to be the plans for the intake headworks (Croes et al. 1895:588). The headworks were designed to maintain normal stream flow adjacent to the canal intake even during periodic floods, and to prevent the accumulation of debris in the area of the intake. Most of the permanent headwork construction had not even been started in 1895, and water was still being diverted into the canal by means of a temporary ditch (Hall 1895:79). Although at least some aspects of the permanent headworks were eventually constructed (their concrete ruins are still visible near SAR 2 -- Foster et al. 1989:12), it is not now known if the headworks were ever completed exactly as planned. The headwork description in the succeeding paragraphs is according to the plans, not necessarily a description of what was built.

According to the plans, the stream flow of the Santa Ana River was to be directed to the intake by a diversion dam stretching diagonally across the canyon. The dam itself was to be rather low, with sloping sides and a rounded top to allow flood waters to escape more easily (Hall 1895:80-81). The first tunnel of the canal was to receive water from a long bay, 60 feet long by 12 feet wide, that in turn would receive water from almost the whole length of the river by-pass channel that was formed on the downhill side by the diversion dam. The bay was to be separated from the by-pass channel by a partition of movable weir shutters that would control the flow of water into the bay and hence the intake tunnel (Hall 1895:79-80).

It is likely that the headworks were never completed as planned. Bear Valley Irrigation Company never recovered from its financial difficulties. It would appear that the canal itself was abandoned in 1899 due to company cost overruns and problems with the wooden siphons (Hornbeck and Botts 1988:12-13). The intake tunnel, however, would later be incorporated into the conduit system for SAR 3. The tunnel was finally abandoned altogether after the 1916 flood, when it was replaced by a parallel tunnel that had been started but not finished by the Mountain Power Company in 1892 (Hornbeck and Botts 1988:23-24). The old Santa Ana Canal intake tunnel is still visible today, located just downstream from Santa Ana River No. 2.

The dry years of the 1890s and early 1900s spurred the demand for more water in the San Bernardino Valley. In 1903, the Bear Valley Mutual Water Company was formed to construct a higher dam for the Bear Valley reservoir and revive at least parts of the old Santa Ana Canal. The survey for the new dam was conducted around 1909 (Finkle 1910). The new multiple-arch dam was raised in 1910-1912 and was 19 feet higher than the old construction (Fowler 1923:591; Hinckley 1983:1-2,9). By this time, the Santa Ana River powerhouse system was fully operational and the Bear Valley High Line Canal had been incorporated into the powerhouse conduit system.

The Santa Ana Canal presaged the conduit system of the Santa Ana River powerhouses. Much of the technology and techniques used in the powerhouse system were first tested with the Santa Ana Canal. This was particularly true in the construction of flumes and the digging of tunnels. More specifically, much of the conduit system for SAR 3 was already in place as a result of the construction of the Santa Ana Canal. Although a short-lived failure, the Santa Ana Canal helped ensure that the hydraulic system of the Santa Ana River powerhouses would be a success. Eventually, parts of the old canal were revived, and to this day, the Bear Valley Highline Canal leaves the forebay of SAR 3 on its way to the Redlands area.

Organizational Beginnings

Agitation for a hydroelectric facility in the Santa Ana Canyon can be traced in the pages of the Redlands newspaper, *The Citrograph*, at least as far back as 1891. Similar interest was also expressed in Los Angeles, which was beginning to look for new sources of hydroelectric power all along the mountain rim of the Los Angeles Basin (Secord 1985:8.4).

The Southern California Power Company was organized in December 1896 for the purpose of tapping into the hydroelectric potential of the Santa Ana River (Low 1903:13). By another account, the company was incorporated in April 1897 (Secord 1985:8.2). The Southern California Power Company let the contract for the Santa Ana River powerhouse, now known as Santa Ana River No. 1, in the spring of 1897 (Low 1903:13). By June of that year, with construction underway, the company had a bonded indebtedness of a half million dollars (Secord 1985:8.2).

The people operating the Southern California Power Company were virtually the same as the officers of the Redlands Electric Light and Power Company (Low 1903:13). Henry Fisher served as president of the new company; H.H. Sinclair was the general manager; E.M. Boggs was placed in charge of the hydraulic work; while O.H. Ensign served as electrical engineer (Transmission Plant 1899:335). It is believed that Sinclair himself obtained the water rights to the canyon (Secord 1985:8.9).

In 1898, with construction well under way, the Southern California Power Company merged with the Edison Electric Company of Los Angeles in such a fashion that it became a wholly owned subsidiary of Edison but retained its own identity. This occurred in either April (Low 1903:13) or June (Trott 1919:17; Secord 1985:8.5). In July 1902, Southern California Power was completely absorbed by the Edison system (Secord 1985:8.5), and its officers went on to positions in the Edison system.

Although there is no documentation to prove collusion, it has always been believed that even at the planning stage of SAR 1, there was some sort of gentlemen's agreement between the officers of the Redlands Electric Light and Power Company and Southern California Power Company, on the one hand, and the directors of the Edison Electric Company of Los Angeles, on the other. The nature of the agreement can only be guessed, but it seems likely that Edison agreed to purchase the Santa Ana River plant after construction, or simply absorb the assets of the Southern California Power Company when the plant was completed (Myers, personal communication 1992). This much is clear: from the first, Santa Ana No. 1 was planned as a large facility, bigger than anything that Redlands needed in those days. According to the later recollection of O.H. Ensign, the site for SAR 1 was selected as early as the fall of 1896, and even then it was proposed that there would be a high-voltage transmission line to Los Angeles (Secord 1985:8.6).

Construction and Original Layout of SAR 1 Features

Construction of the Santa Ana River powerhouse system began in June 1897. Initial work was limited to the conduit system, in particular the tunnels. The powerhouse itself was not begun until late October (Secord 1985). All construction was performed under the general management of H.H. Sinclair (Low 1903:13). The entire operation was supposed to be completed by January 1898, but this deadline was missed by almost a year due to contractor delays and other financial problems (Secord 1985:8.7). In fact, it may have been due to these problems that Edison made Southern California Power a formal subsidiary in 1898, as a guarantee that the work would be completed.

The schedule of the construction work is now impossible to recreate in any detail. Since work on the conduit began before work on the powerhouse, it seems most logical to describe the construction details and the original layout of the system in roughly that order, beginning at the intake and proceeding to the powerhouse itself.

Intake/Headworks

The headworks of SAR 1 were built immediately above the juncture of Bear Creek with the Santa Ana River, about seven miles below the Bear Valley dam and at an elevation of 3422 feet (Lighthipe 1899:5; Fowler 1899:146). In actual fact, there were always two intakes, one on the Santa Ana and the other on Bear Creek.

The Santa Ana River diversion dam was a low masonry construction topped with sandbags. The bags would wash away in any flood and so protect the intake system and possibly the dam itself. The diverted Santa Ana water went into a masonry intake that supported a heavy grating of old railroad rails. Below the rails were a pair of gates designed to regulate the amount of water admitted to the wooden flume. The flume was cemented into the masonry intake, and extended from there some 372 feet to the junction with the Bear Creek flume (Fowler 1899:146).

Initially, the diversion of water at Bear Creek was done without a dam. The head of the flume there had a masonry intake, with its own grating of rails and regulating gates. A hopper-shaped depression was set into the flume, equipped with a discharge gate, that was used to trap rocks and remove them from the conduit system (Fowler 1899:146).

This intake system was demolished by the 1916 flood. In the years that followed, impounded water from the Santa Ana was transported across the juncture of the two streams and emptied into a small reservoir created by a diversion dam on Bear Creek (Fowler 1923:591).

The original intake sand box was situated at the beginning of the conduit system, after it had safely cleared the bed of the river. In the case of SAR 1, the sand box was located between Tunnels 1 and 2. It was 121.5 feet long and 29 feet wide, divided by a central partition into two compartments, 14 and 15 feet wide (Figure 10 and CA-130-32). Each compartment had a gate at both ends. At the bottom of each compartment were two hopper-shaped depressions, 5 feet deep at the shallowest part and 9 feet deep at the base, where the discharge gates were located. This type of sand box was easy to clean; while one compartment was being emptied and sand and rocks flushed out, water would be routed through the other compartment without any interruption in the flow (Fowler 1899:148).

Below the sand box was the grizzly, which measured some 7 by 30 feet. The grizzly caught floating debris within the conduit, which was then removed by a rake that traveled over the grizzly every quarter-minute. The rake was powered by a paddle wheel situated within the conduit (Low 1903:20).

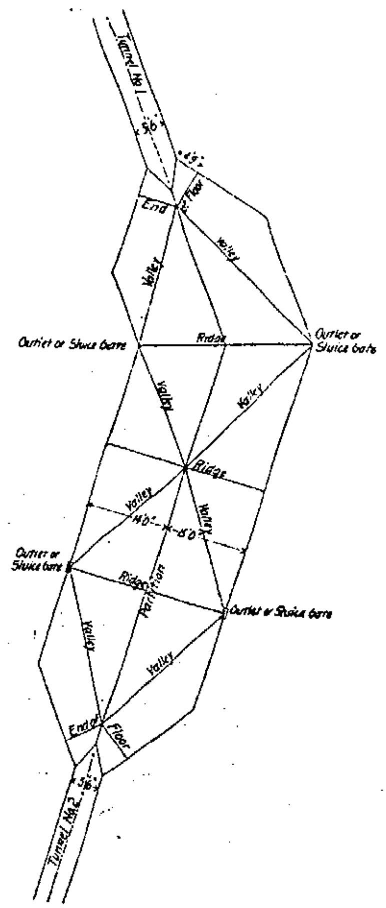


Figure 10. Plan of Sand Box (Fowler 1899:146)

Conduit System/Tunnels and Flumes

From the sand box and the grizzly, the conduit system maintained its gradual grade along the north and northwest side of the Santa Ana River. With the exception of the sand box and an open masonry canal 167.1 feet long, the conduit system consisted of a series of tunnels and flumes between the intake and the penstock area. The drop of the conduit was 9.5 feet per mile (Fowler 1899:146), very close to that used by the Santa Ana Canal. The carrying capacity of the conduit was an estimated 120 second-feet (Low 1903:19).

The chief engineer of the conduit line and the man in charge of its construction was Edward M. Boggs, a civil and hydraulic engineer (Fowler 1899:149). One of his tasks was to supervise the contractors responsible for building the incline and the cableways needed to convey building materials to the work sites along the slope of the Santa Ana Canyon.

The incline proved to be so expensive that the contractor had to relinquish the job. Southern California Power itself was forced to deliver materials to the job sites, and the company switched to cableways. These were 3/4-inch wire rope wrapped around sheave wheels secured at the bottom of the canyon and a timber shear set into the bluff at the top. There were at least three of these cableways in use. The longest had a span of 900 feet. The trolley that operated on the cableway was powered by a single drum engine using compressed air. The second longest cableway was operated by a single drum steam hoisting engine, and the third and shortest, by a horse team (Fowler 1899:148).

The work on both the conduit tunnels and flumes was considered a rush job, since it was imperative to finish the bulk of the work before the rainy season of 1897-1898. For this reason, work progressed on Sundays and holidays. By September 1897, there were some 235 men working in the canyon, with about 3000 feet of tunnels completed. By October, the general contractor, a Mr. Phelm, was unable to pay his subcontractors, forcing tunnel excavation to a halt. Phelm was fired and replaced by Fairchild and Gilmore of Los Angeles (Secord 1985:8.6). Due to this and other delays, the conduit work continued during the dry season of the following year. Some workers even did night shifts during the last seven months of line work, May through November 1898. During this period, Chief Engineer Boggs had to camp in the canyon near the line in order to supervise the work (Fowler 1899:148).

Some 80 percent of the conduit was comprised of tunnels (Lighthipe 1899:5; Fowler 1899:146). The tunnel work began with the survey alignments. Surface location lines were used whenever possible, but for Tunnels 1 through 4, the line and grade had to be calculated by traverse lines and triangulation. Tunnels were excavated from both ends simultaneously, and it was noted that all headings met almost exactly as planned (Fowler 1899:147).

Most of the tunnel work for SAR 1 was done by hand-drilling and was considered difficult. For the most part, explosives were not used due to the easily fractured local rock that left gaping holes in the tunnels that would later have to be repaired with concrete (Fowler 1899:146). Perhaps, too, the adverse results of dynamite were remembered from the construction of the Santa Ana Canal.

The power drills used to excavate the tunnels operated with compressed air. The compressor was located at the bottom of the canyon and was at first powered with a steam engine. Later, water was piped from upstream and then dropped 30 feet to run Pelton wheels that operated the compressor. Air was then piped up the canyon wall from the compressor to the job site (Fowler 1899:146-147).

In the course of the tunnel work, many areas had to be shored with 4 x 6 to 8 x 8 inch timbers placed 4 feet apart. These were left in place until the tunnels were completely excavated and ready for the final concrete work. Only 12 percent of the total tunnel length of the conduit was unlined with concrete; another 12 percent was walled and floored, while the remainder (76 percent) was walled, floored, and arched with concrete (Fowler 1899:147).

Where concrete was used to shore up and streamline the tunnels, the average thickness of the floors was 5 inches; the walls, 7.5 inches; and the arches, 8 inches. Any large cavities in the tunnels were filled with rock and at least partially cemented behind the concrete wall. The wall surfaces were relatively smooth after the removal of the frames; the bottom surfaces were made especially smooth with a 1.5-inch layer of cement mortar, applied with trowels. Alsen's cement was used on those occasions when floors were wet -- and for all work in the penstock area (Fowler 1899:147).

The concrete was mixed with gravel according to where it was to be used. One part Portland cement to seven parts gravel was considered suitable for the walls, while one to five was considered the proper ratio for the arches. Most of the gravels used in the tunnel work were quarried in the canyon, from a site near Tunnel 12. Gravel sacks, which had been prepared by the first subcontractors, had been put on line by the incline railroad (Fowler 1899:147).

The Portland cement used at SAR 1 came from Mt. Slover, identified as the "Colton Mines" (Transmission Plant 1899). About 8500 barrels of cement were used in the tunnel work alone. The cement set so quickly that it had to be mixed with water in the tunnels themselves. The cement and gravels were mixed dry outside and then pushed into the tunnels where water was added. Water for the cement was pumped from the river to a height of 550 feet; Tunnels 7 and 8 were so far up the canyon wall that water had to be hoisted on the cableway in barrels (Fowler 1899:147).

The mold frames for the concrete walls of the tunnels were formed by 2 x 6 inch uprights that were 5 to 6 feet long and placed 4 feet apart. The uprights were braced across the top by 2 x 3 inch struts held in place at the top with wedges inserted into the space between the uprights and the rock wall. At the bottom, the uprights were wedged against the tramway tracks. The lagging boards, surfaced on one side, measured 1.25 x 12 inches by 12 feet. These boards were placed in position behind the frames just before the concrete was added. They were left in place for two to three days until the uprights and boards could be removed (Fowler 1899:147).

The barrel-vaulted tunnel arches were shaped by forms supported on short posts about 4 feet apart. On the forms, narrow strips of lagging, each 12 feet long, were laid on each side, starting at the base of the vault curve. Concrete was tamped into these spaces just as it had been applied for the walls, moving up the arch about 12 inches at a time. The last 18 inches, which comprised the arch cap, were formed with lagging strips that were only 4 inches long. The spaces created by these forms were filled in from the end. The arch forms were left in place at least one day longer than the sides to ensure that they set properly (Fowler 1899:147).

When finished, the tunnel sides rose 4.5 feet above the floor, which was itself 4.5 feet wide. When each tunnel was completed, its portals were fashioned with boulders and cement. The first tunnel had a heavy gate positioned at the portal, which could be closed in case of flood (Fowler 1899:146).

Eighteen tunnels were constructed along the SAR 1 conduit line. As with the Santa Ana Canal, the tunnels were each given a number, beginning with the intake. The total length of these tunnels was 11,555.4 feet; the longest, Tunnel 8, was 2074.2 feet long (Fowler 1899:146).

A series of flumes connected the 18 tunnels. Extensive tunneling was preferred over a 100 percent flume system for two reasons: a flume system would have been too expensive and too long. With all the spurs that had to be rounded, it was feared that a serious loss of head would result if a complete flume system had been used (Fowler 1899:146).

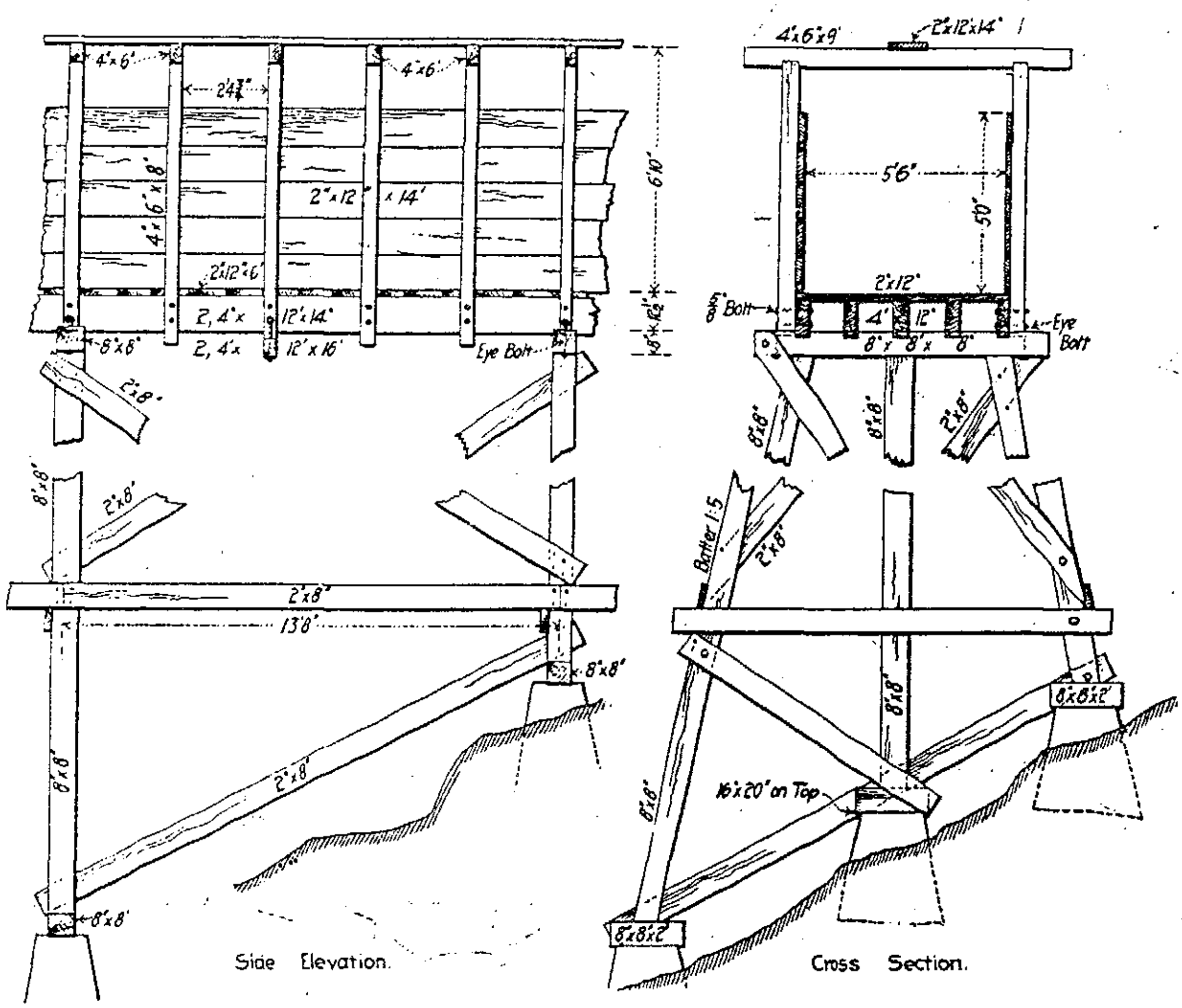
The flumes between the tunnels were 5.5 feet wide (Figure 11), with the one exception of the flume between Tunnels 10 and 11, which was only 44.2 feet long and thus narrowed to 4.5 feet. The flumes were thus one foot wider than the finished tunnels, which compensated for the bends in the flumes and the roughness of the flume surfaces. The sides and the bottoms of the flumes were formed with 2-inch redwood planks; the posts and caps that held the flume in place were made of 4 x 6 inch redwood beams. Originally, the flume walls above the curved bottom were formed by four 12-inch planks with the option for another two planks if more water was added to the conduit system (Fowler 1899:147).

Flume curves were made by a slight deflection in each of the planks that made up the curved portion. The joints were caulked with oakum on the inside and tarred along the joints on the outside to help retain the oakum (Fowler 1899:147).

The flumes themselves rested on concrete piers or "walls placed transversely to the line." These concrete structures were set to a depth of 12 feet or more to protect against slippage on the steep canyon side. The concrete foundations were usually placed 13 feet 8 inches apart; on benches, they were about half that distance. Gullies were crossed with spans of hog chain trusses placed every 27 feet 4 inches (Fowler 1899:147).

The first flume, adjacent to the intake, was 5 feet wide and 3 feet deep. Unlike the others, the top was covered with planking for a distance of 90 feet from the intake, until the bed of the river was low enough for its water to flow below the flume. This planking was to prevent damage to the conduit system that might result from high flood waters. This way, flood waters could safely go over the flume (Fowler 1899:146).

Figure 11. Flume Construction
(Fowler 1899:147)



There were 20 flumes within the SAR 1 conduit line, for a total length of 2661.6 feet. The longest flume, 956.4 feet, was located between Tunnels 4 and 5. It was partially roofed with planking to protect the flume from rock slides, which were common in that particular location. Almost from the beginning, it was proposed to replace this flume with a tunnel that would create a more permanent solution (Fowler 1899:146-147).

From the end of Tunnel 18, the last flume on the conduit system extended 265.5 feet to the reservoir at the head of the penstock. This flume had walls that were six planks high to contain the extra water that would back up before the penstock.

Just above the penstock reservoir, a spillway was created by leaving off the top plank for a distance of 38 feet. This excess water would then flow into a concrete chamber and enter a 24-inch diameter pipe, No. 8 gauge, where it would drop to the canyon below (Fowler 1899:147).

Reservoir, Forebay, and Pressure Pipe

The last flume connected with the reservoir and forebay that were found just above the pressure pipe, more commonly known today as the penstock. Together, the reservoir and forebay comprised 56.9 feet between the conduit system and the pressure pipe (Fowler 1899:146).

The purpose of the reservoir was to calm the water before it entered the pressure pipe. The reservoir was triangular in shape, 60 feet to a side and 9 feet deep. Two of the three sides were formed by excavations into the side of the canyon wall that were then surfaced with concrete. The third wall faced out, away from the canyon, and was concrete, 2 feet thick at the top and anchored 16 feet below the surface of the cliff. The last sand trap for the conduit system was located at the base of the reservoir. There, a by-pass could be used to deliver water to the penstock while the sand was being removed (Fowler 1899:147-148).

The forebay was located along the exposed third wall of the reservoir. It was always kept submerged to keep air out of the pressure pipe. The SAR 1 forebay had two compartments separated by a gate valve (Drawing 4269). The 30-inch pressure pipe exited from the first forebay compartment in a steep downward trajectory toward the powerhouse. The second compartment was designed for another 30-inch pipe in case the powerhouse ever needed more water (Fowler 1899:147). It should be noted that although SAR 1 now has two pressure pipes, and was planned for two, it was originally built with just one.

The pressure pipe itself was built in segments, starting at a point about 75 feet from the powerhouse. Work on the pipe then proceeded up the canyon wall toward the penstock. All vertical and horizontal changes in the pipe's direction were made at the same time to minimize the water resistance. A No. 10 gauge steel was used at the top of the pipeline, which increased to a 9/16-inch thickness at the base, which had to withstand greater pressure. The longitudinal seams of each segment were double-lap riveted; the round seams where the segments joined were single-riveted. The pipe was then protected by a mixture of asphaltum and crude oil before it was buried to an average depth of 7 feet inside the canyon wall. When this was done, the last joint of the pipeline was connected to the receiver pipe by means of a riveted collar. Upon completion, the pressure pipe had a total length of 2214 feet from the forebay to the receiver, with an inside diameter of 30 inches (Transmission Plant 1899; Fowler 1899:148; Low 1903:21).

The static head of the pressure pipe has been cited as 735 feet, although it appears that the effective head was somewhat less that this, anywhere from 700 to 728 feet (Transmission Plant 1899; Lighthipe 1899:5-6). Water could be shut off at the head of the pipeline by means of a metal plate operating within brass slides. The gate was closed with oil kept under pressure by a pipeline extending from an oil storage tank another 127 feet farther up the canyon slope. Oil was used because it would not rust or freeze. In 1903, this gate was operated electrically, by means of a push button within the powerhouse (Low 1903:21).

Receiver

The base of the pressure pipe was connected to another pipe set at a right angle. The latter pipe was originally known as the receiver, but is now commonly referred to as the header. It was located just outside the powerhouse and ran the length of the building. Where the pressure pipe and the receiver joined, there was an Eddy gate valve. Also connected to the receiver was a second valve adjacent to the first, just in case a second pressure pipe was ever installed (Fowler 1899:148).

The receiver, like the penstock, had a 30-inch diameter. It was lap-welded, with flange joints that had been machined for the best possible fit. Ludlow valves were installed between the receiver and the six outlet pipes that led into the powerhouse. In 1899, the effective head of the pressure pipe was 728 feet, which created water pressure within the receiver that was calculated to be 314 pounds per square inch (Fowler 1899:148). Under this pressure, water was forced into the outlets and thence through the nozzles. Each nozzle was aimed at a water wheel by means of an axle and ball joint, situated between the outlet pipe and the nozzle (Dennis 1914:607). The outlets were tapered from 10 inches at the receiver end to 6 inches at the nozzle connections. The nozzles themselves were tapered to a diameter of just over 3 inches (Fowler 1899:148; Transmission Plant 1899:335). By the time the water shot out of the nozzle, it had enough force to cut a man in two (Myers, personal communication 1992).

The only drawback to the layout of the pressure pipe, receiver, and outlets was the number of right angles the water had to make before it reached the nozzles. Only one nozzle received water from directly in front of the pressure pipe. At first there was some fear that these right angles would significantly increase the friction the water would have to overcome and so decrease the effective head. In 1899, after the system was started up, it was discovered that this problem was less serious than first calculated (Fowler 1899:148). In 1903, it was estimated that there was "practically no pressure drop" as a result of these right angle turns (Low 1903:21).

From intake to outlet, this was the water conduit system first employed for SAR 1. Even though the intake works were later replaced after major floods and the wooden flumes were later replaced by metal, the basic system remained the same, with two rather temporary intakes on both the Santa Ana River and on Bear Creek. In the early years of the SAR 1 operation, there were plans to create a permanent reservoir for the intake by building a steel dam just below the juncture of the Santa Ana and Bear Creek at a location where the canyon had vertical walls at least 200 feet high (Transmission Plant 1899:335; Fowler 1899:146; Low 1903:19).

This reservoir was never constructed. After the floods of the 1910s, and especially the 1916 flood, there appeared to be no more talk of such a dam and reservoir. Thereafter, Edison made do with the temporary intakes that first served the system -- temporary intakes that were not so costly and could be replaced quickly. By this time, the best formula for operation of the powerhouses had been time-tested: the intake structures would remain relatively temporary and easy to fix; only the powerhouse structure would be permanent.

5. POWERHOUSE CONSTRUCTION

The SAR 1 water conduit system entered the powerhouse just above the juncture of Keller Creek with the Santa Ana River. In 1899, the elevation of the powerhouse was uniformly given as 2670 feet AMSL (Fowler 1899:146; Lighthipe 1899:5). In the 1920s, the elevation was recorded as 2765 feet AMSL (Fowler 1923:592). According to modern topographic maps, the elevation is approximately 2740 feet AMSL. Although the elevation of the powerhouse has not changed since its construction, the elevation of the land around it almost surely has been increased by alluvial deposits left from the major floods of the twentieth century.

Physical Plant

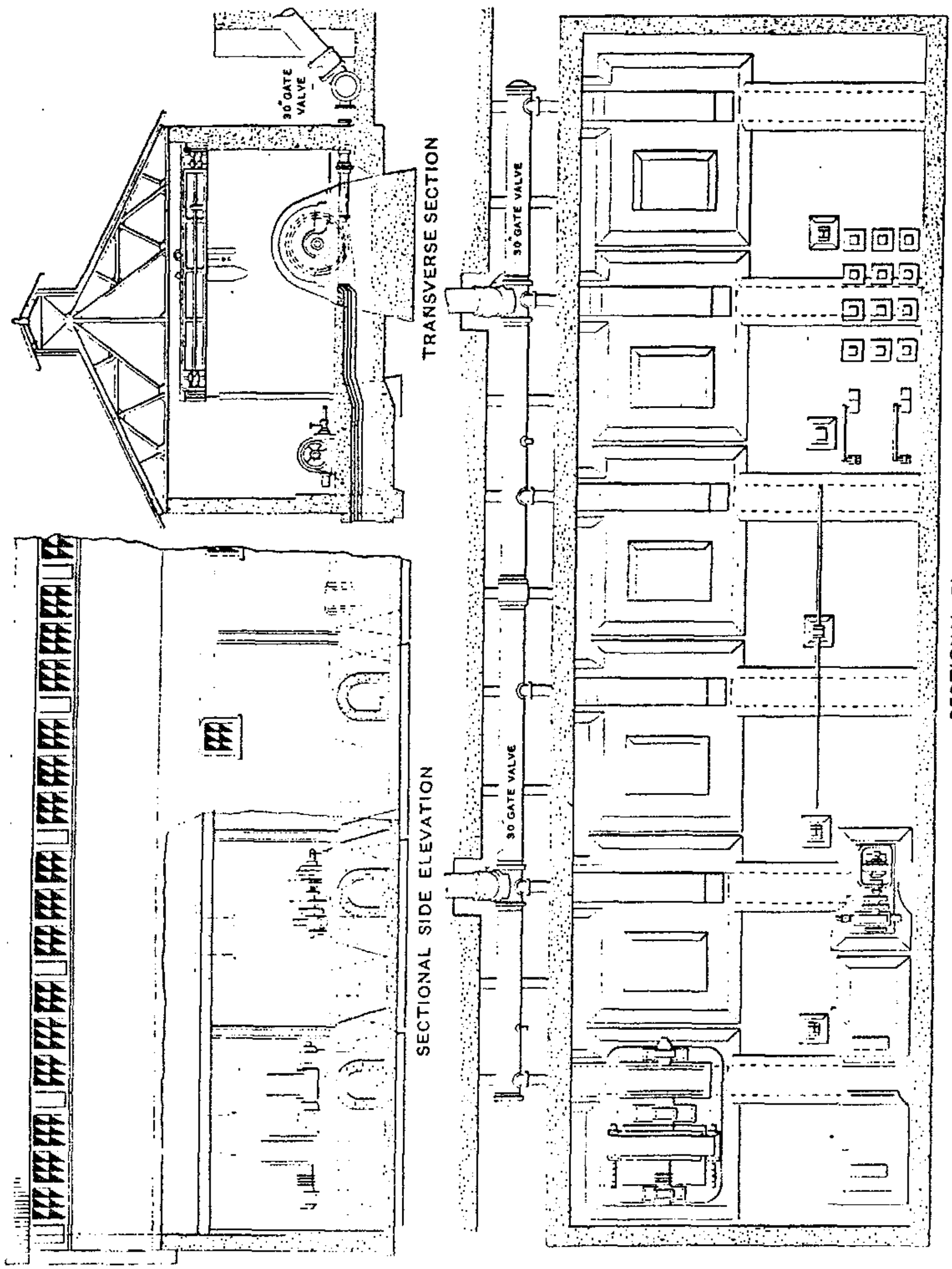
The layout of the facility incorporated a number of innovations for the time. The receiver, which extended the length of the building, was one of the innovations. So too was the piping for each wheel, which was flanged onto the receiver and entered the powerhouse separately. Also too, each wheel had its own tail race. The individual tailraces were then designed to join together on the other side of the plant (Lighthipe 1899:5).

Powerhouse construction began in mid-October 1897, with work performed by T.E. Thornton and C. Leonardy of Redlands (Secord 1985:8.6). The building was designed as a rectangle in plan, with exterior measurements of 130 x 41 feet and interior measurements of 127 x 36 feet (Fowler 1899:148; Low 1903:28). The long axis of the building was oriented roughly east-west, parallel to the receiver.

The floor was concrete with a cement surface. The walls were of monolithic concrete, formed with a mixture that was one part Portland cement to five parts gravel. No iron reinforcement was used. The wall against the cliff side and the receiver was a uniform thickness of 2.5 feet; all other walls were 2 feet thick to a height of 4 feet above the floor, and 18 inches thick above that (Fowler 1899:148; Low 1903:28). The main door to the powerhouse was located on the west wall, with a much smaller door on the east side, near the north end.

The powerhouse was designed to contain six waterwheel/generator units, all located along the thick cliff-side wall, which was pierced by outlet pipes from the receiver (Figure 12). Despite this design, only four units were ever installed in the plant. These were positioned along the thick wall, with Unit 1 located in the northeast corner of the building, followed by the other three units. When the facility began operation, the northwest corner, designed for Units 5 and 6, contained the machine shop area; it now contains the modern switchboard.

Figure 12. Plan and Profile of SAR 1, 1899
(Lighthipe 1899:4)



The north wall was made especially thick to compensate for the additional weight of the metal crane which operated along a recessed track in the wall (Fowler 1899:148). The hand-powered traveling crane was used to lower the water wheel/generator units into place and to remove them for any repairs. The crane span was 26.5 feet long with a 15-ton capacity. On the south side, the crane span was supported by another track resting on free-standing iron columns inside the building (Fowler 1899:148; Low 1903:28). At least one of the steel columns bears the imprint of Carnegie Steel, suggesting that it was transported from Pennsylvania (Hamilton, personal communication 1992).

Above the walls and the crane was the metal single-gable roof supported on steel-riveted trusses. Wood purlins located above the trusses carried the galvanized corrugated iron covering that formed the roof and the two gable sides. The peak of the roof was broken by a rectangular "monitor roof" that extended the length of the building. This monitor roof was 5 feet wide and 4 feet high; its sides were covered by windows to provide lighting and ventilation (Fowler 1899:148; Secord 1985). Lighting was also provided by five windows set high up on the south wall.

Water Wheels, Governors, Tail Races

The first water wheels used at SAR 1 were supplied by the Pelton Water Wheel Company, which also furnished the governors for the exciters (Low 1903:29). The water wheels were placed into position with the traveling crane, with the operation overseen by the hydraulic engineer, E.M. Boggs. The wheels were installed as early as March 1898, according to the original contract (SAR 1, 1909-1945). Each water wheel was set beside its own generator, with both wheel and generator positioned on a single bed plate (Lighthipe 1899:5). Both wheel and generator shared the same shaft, which was stabilized by three bearings: two on the ends, and one in the middle between the wheel and the generator (CA-130-J-48).

Each water wheel was classified as the Pelton-impulse type, 82 inches in diameter. Each weighed 12,500 pounds, with the center of cast-steel, "turned all over to give it an accurate balancing" (Transmission Plant 1899:335). The 21 buckets of each wheel were attached with 1-inch bolts driven into turned reamed holes. The buckets were of soft cast-steel (Transmission Plant 1899:335). Once installed and checked, each wheel with buckets was enclosed in casing for protection (Fowler 1899:148).

Also fitted onto each wheel was a Type F Lombard water wheel governor, believed to be the first manufactured with that name (Low 1903:28). This type of governor is believed to have been designed by James Lighthipe. The function of the governors was to aim the nozzle at the buckets of the wheel and deflect its aim when the load fell off (Fowler 1899:148). The governor was designed to operate the wheel at an estimated 300 revolutions per minute (SAR 1, 1909-1945). The Lombard Governor Company of Ashland, Massachusetts, made the most popular hydraulic speed control units in the first decades of the twentieth century. In the 1920s, this honor went to the Woodward Company of Rockford, Illinois (Hay 1991:I:89).

The Lombard governors were connected to a main valve lever, designed so that as the load was applied at the main station, the lever was moved along by the governor, which opened the valve further, allowing more water to hit the wheel. The goal was to apply more force to the wheel as the electrical load increased, without varying the speed of the water wheel itself (Fowler 1899:149).

The governor was activated by a head of water that ranged from around 120 feet to 300 feet, according to the accounts left by two sources. The water was drawn from the main pressure pipe into a small settling tank or reservoir, located adjacent to the pressure pipe (Lighthipe 1899:8; Low 1903:28).

After the water hit the water wheel buckets, it was discharged underneath the floor of the powerhouse, each water wheel having its own tail race 4 feet 4 inches wide (Drawing No. 5282). Water in the tail race was kept about three feet below the buckets to keep the discharge water away from the water wheel (Figure 13). Before the electrical load was applied to the generator, the tail race had to bear the full brunt of the water discharge, with water splashing 30 to 40 feet in the air. This was such a serious problem that the top of the tail race was lined with steel plates and covered with timber in 1899, replaced by 1903 with boiler plate to a point about 75 feet away from the water wheels. Even in 1899, a wooden buffer was placed on the wall of the tail race reservoir opposite each nozzle to protect the concrete from the impact of the water. As the electrical load was applied and the wheel was engaged, the water force was expended against the buckets, and water in the tail races ran more quietly (Fowler 1899:148-149; Low 1903:28).

After exiting the powerhouse, water from all four tail races would join in a concrete canal that was listed by one source as 8 feet wide (Fowler 1899:148; Figure 14), and other as 12 feet wide and 10 feet deep (Low 1903:28). According to an engineering drawing dated to 1910, the tail races ran into a canal that was 8 feet deep and 10 feet wide (Drawing No. 5282). From this point, the water was of no concern to the powerhouse: in 1899, it returned to the river via a sluice gate (Fowler 1899:148), but within a few years, it was redirected into the conduit system for SAR 2.

Figure 13. End Section of SAR 1
(Low 1903:25)

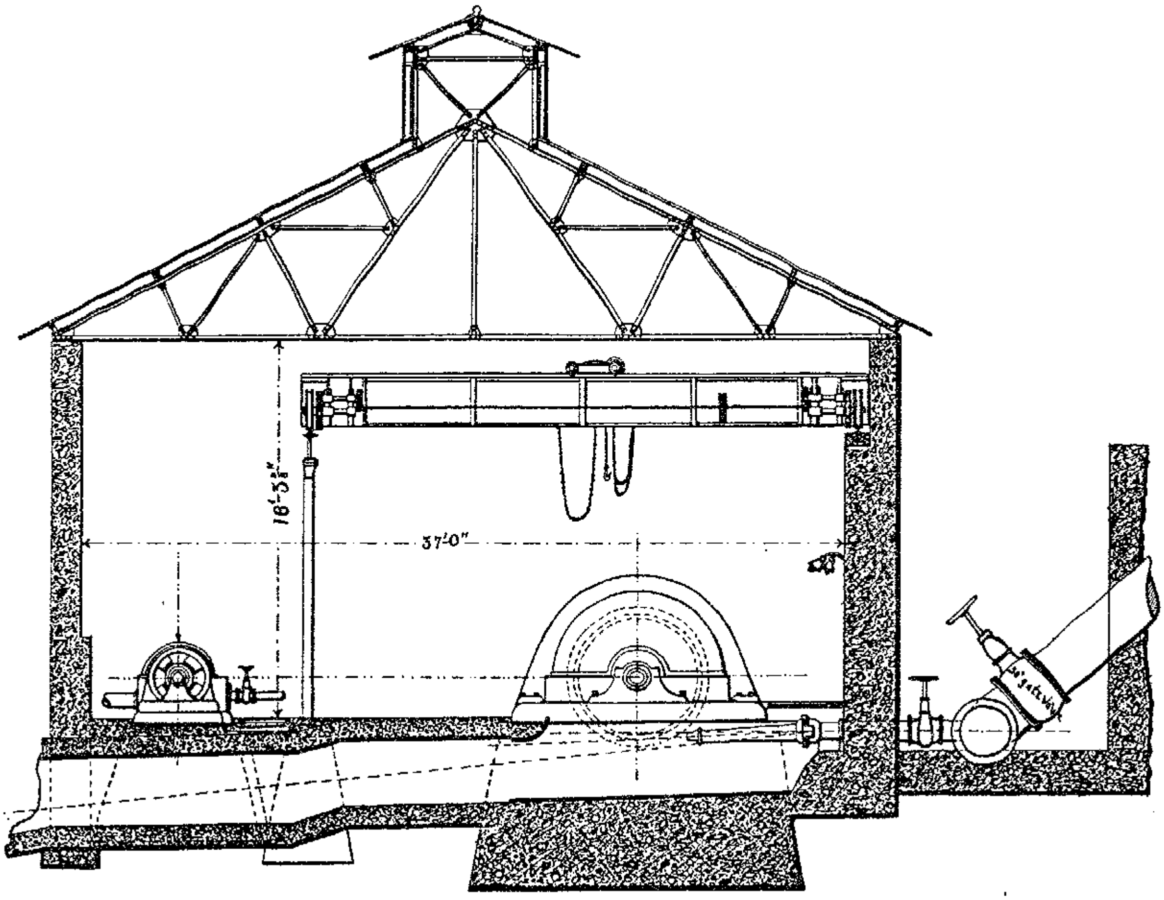
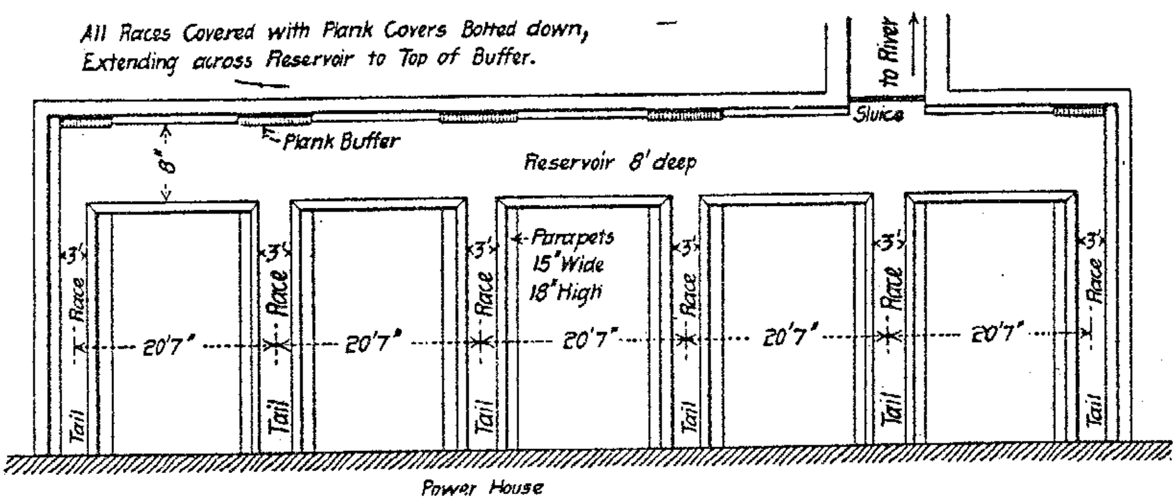


Figure 14. Plan of Tail Races
(Fowler 1899:148)



Generators

As mentioned above, the four generators were directly connected to the water wheels and mounted on the same base plate (Fowler 1899:148). All four were made by General Electric according to specifications outlined by the chief electrical engineer, Orville Ensign (Secord 1985:8.6). The generators were the rotating field type. With revolving field generators, the electromagnets are part of the rotor portion of the generator, while the armature is part of the stator (CA-130-J-51). In other words, the wire windings remain stationary while the electromagnets spin inside the orbit of the windings (Fowler 1899:148; Lighthipe 1899:5). The armatures of the Santa Ana No. 1 generators were "Y" connected (Low 1903:28), which meant that there were three wires and a ground.

Each of these three-phase generators had a 750 kw capacity and were rated at 300 revolutions per minute. The 20-pole revolving fields were excited by a 125-volt current that was "brought to the generators through two contact rings on the shaft" (Lighthipe 1899:5). The current was then imparted to the shaft and its revolving fields by a series of carbon brushes, similar to those used in railroad motors. Excited in this fashion, each generator was wound to produce 750 volts at 50 cycles per second (Fowler 1899:148; Lighthipe 1899:5,13). At the time of their installation in March 1898, these generators may have been the largest of their kind in the world (Secord 1985:7.9; SAR 1, 1909-1945).

The General Electric generators used at Santa Ana No. 1 were essentially modern in design. Their configuration of windings on the stator and electromagnets on the rotor, was the reverse of the arrangement used at Mill Creek (and Niagara Falls). The Santa Ana configuration became the industry standard in the years to come.

Exciters

The electromagnets of the four generators were powered by three General Electric 30 kw four-pole exciters, each wound for 125 volts. In order to energize the electromagnets, the exciters had to produce direct current. Originally, the exciters were like miniature versions of the generators, each direct-connected to its own small water wheel. These wheels were made by the Pelton Water Wheel Company in 1897, according to labels still visible on the casings. The wheels were rated at 50 horsepower (Fowler 1899:148). Each exciter had its own water piping, with small tail races provided by 10-inch iron pipes (Lighthipe 1899:7). These water-driven exciters were located in the southwest corner of the powerhouse.

The exciter water wheels were controlled by small mechanical Replogle governors (Lighthipe 1899:8). According to Fowler, these governors were designed by the superintendent of the Southern California Power Company, Orville Ensign. The three exciters were further controlled by a separate panel on the switchboard. In 1899, these exciters also provided current to light the powerhouse at night (Fowler 1899:148).

Wiring, Switchboards, and Transformers

All wiring from the generators and the exciters went to the switchboard through a fiber conduit laid underneath the concrete floor of the powerhouse. In 1899, there were two switchboards within the powerhouse: the low potential switchboard and the high potential switchboard. The former, also known as the low tension board, was made of marble and located on the ground floor, immediately south of the generators (Figure 15 and CA-130-J-39). This board had a panel for each of the four generators and was capable of handling the 750 volts that each generator produced. Each panel had three single-pole quick-break switches with two sets of main bus-bars. With this, any combination of generators or transformers could be isolated if trouble occurred anywhere within the system (Lighthipe 1899:7; Fowler 1899:148). The high potential switchboard was located on the balcony above the low potential board. This board was also made of marble, with a heavy marble barrier between the switches (Lighthipe 1899:7).

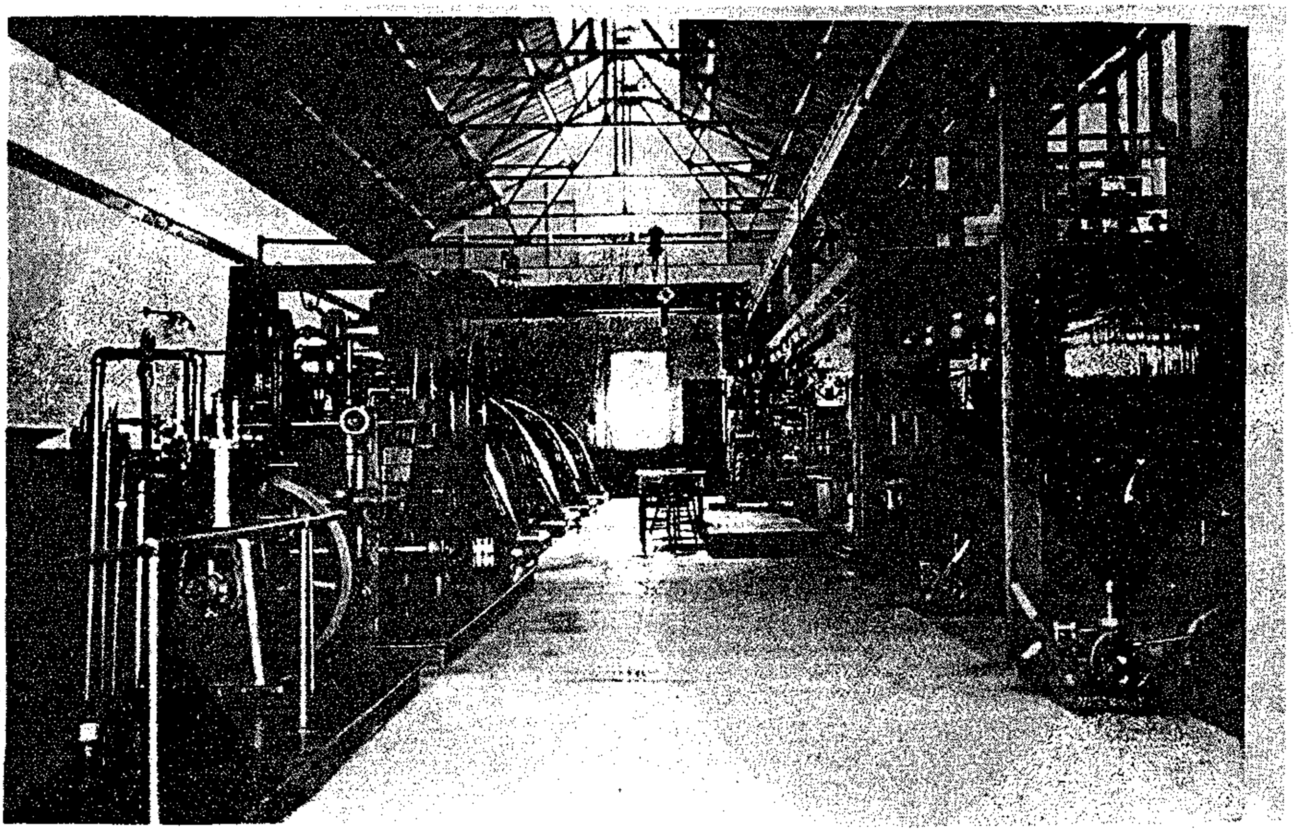
The original switches were all identified as the quick-break knife type (Low 1903:29). There were no oil switches in the original layout of the powerhouse. Even the switches for the 33,000-volt line were of the knife type, identified by at least one source as "hornbreaks" (Hinson 1956:23).

To protect the powerhouse equipment in case of switch failure, there were six fuses on the switchboards, one for each of the six line wires that left the plant. The fuse wire was the so-called No. 20 type, made of pure aluminum and three feet long. Each length went through a wooden tube and had switch contact with the line wire at each end. A screw socket was located at the center of each length, so that a wooden handle could be inserted in case the lengths had to be removed (Fowler 1899:149).

The low tension switchboard also had the usual voltmeters and ammeters; there was also a Thompson recording watt-meter for each set of bus-bars (Fowler 1899:148). The low tension wiring was 700,000 circular mils cable, which went from the switches to the transformers via an air duct that extended under the floor (Low 1903:29).

The 750-volt current generated at the powerhouse was stepped up to 33,000 volts by 12 250 kw General Electric transformers operating at 50 cycles. These transformers were air-blast cooled and situated in groups of three in the southeast corner of the

Figure 15. Interior of SAR 1 Powerhouse, 1909
Original Switchboard at Right
(Finkle 1910:46)



powerhouse, in an area then identified as the "transformer pit" (CA-130-J-46). In this area, the foundations of the transformers were a series of steel beams and concrete supports raised 30 inches above the powerhouse floor to accommodate the air blast ducts and the low tension wires. It also allowed workmen access to the underside of the huge transformers (Fowler 1899:148-149; Low 1903:29). Foundations were laid for another two banks of three transformers each (Fowler 1899:148), but these were never needed since generating units 5 and 6 were never installed.

The air blasts required to cool these transformers were provided by two 80-inch air blowers made by the Buffalo Forge Company, Heating and Ventilating Engineers, of Buffalo, New York. Each blower was powered by a three horsepower General Electric induction motor, made in Schenectady, New York (Fowler 1899:148-149; Lighthipe 1899:5-7).

The 12 transformers operated in a two-step process to jack the current to 33,000 volts for transmission. The transformers themselves raised the voltage from 750 to 19,000 volts. With the primaries connected delta and the secondaries connected "Y," they produced a full potential of 33,000 volts (Figure 16).

After the voltage was stepped up to 33,000, the current passed through the high tension switchboard on the balcony. Unlike the low tension board, which had four panels, one for each generator, the high tension board had only two. Each had a line panel and a connecting panel between them so that the two sets of bus-bars could be thrown together to make one complete board (Fowler 1899:149; Lighthipe 1899:7). After passing through this last board, the six wires of the two main lines passed out of the building through six large terracotta pipes set into the wall at the west end of the building (Lighthipe 1899:7-8).

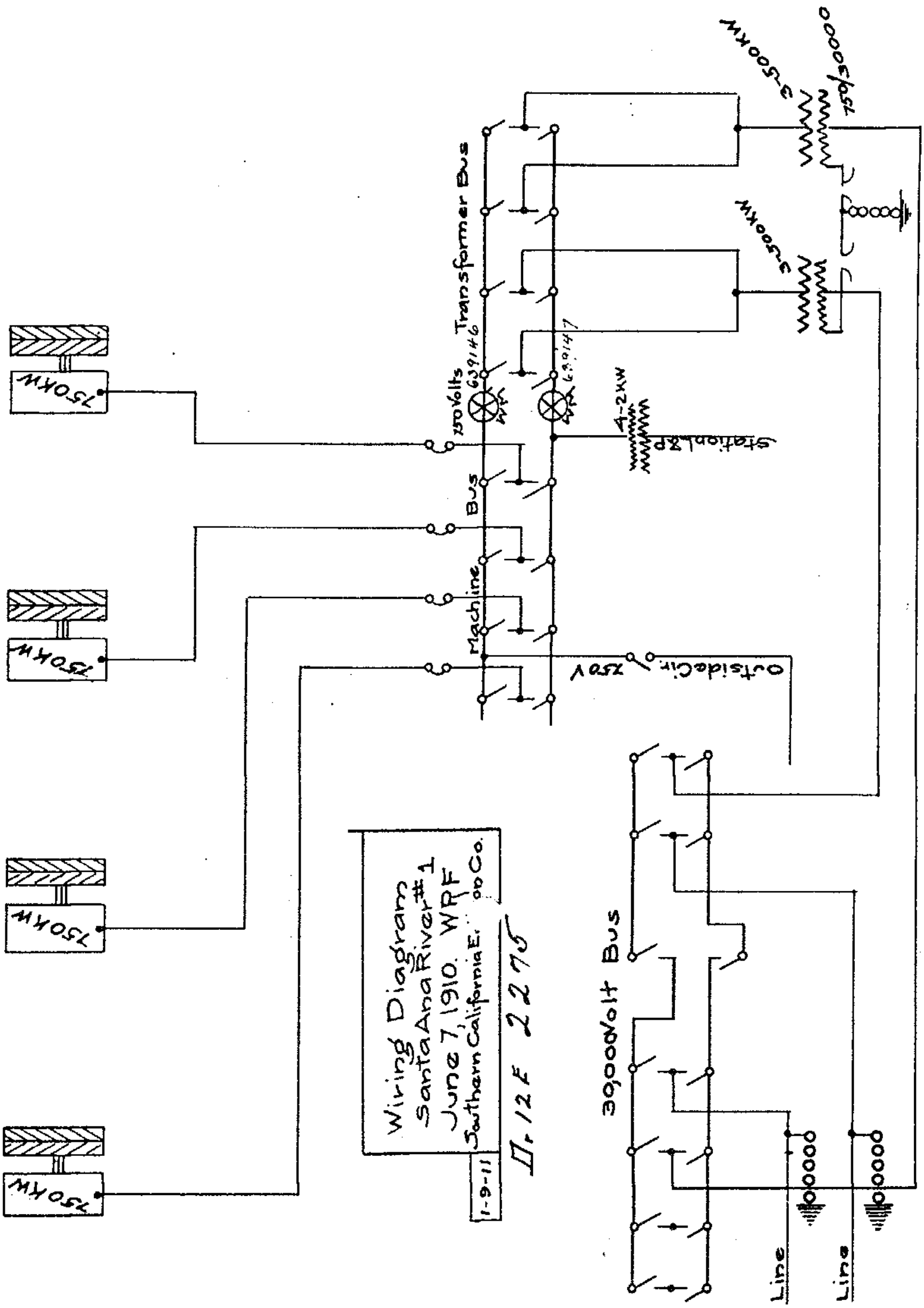
Orville Ensign and the Development of the Transmission Line

One of the most important and famous features of SAR 1 was the transmission line that left the powerhouse, extended down the canyon, out onto the San Bernardino Valley, and thence along the tracks of the Southern Pacific Railroad to Edison's Second Street substation on the west side of Los Angeles, a total distance of 82 or 83 miles (Lighthipe 1899:5; Low 1903:29). This was by far the longest transmission line in the United States at the time the plant came on line. At 33,000 volts, it was also one of the most powerful; the Provo Canyon plant in Utah had a transmission line that could withstand greater pressure (40,000 volts), but the transmission line was not nearly as long as the Santa Ana line (Bly 1898; Myers, personal communication 1992). Before the Santa Ana transmission line proved itself in operation, it was opposed by most electrical manufacturers as a risky proposition. Until then, the most powerful transmission lines were barely above 10,000 volts. This revolutionary advance in the development of electrical transmission was proposed and pushed by the electrical engineer most commonly associated with the Santa Ana No. 1 powerhouse, Orville H. Ensign (Low 1903:29-30; Myers 1986:38).

Orville Ensign was born in 1863 in Ithaca, New York. By 17 years of age, he was studying mechanical engineering at Cornell University, after which he worked in a machine shop in Ithaca and the Schenectady Locomotive Works in Schenectady, New York. In 1885, he joined the Edison United Company, which was reorganized three years later as the Edison General Electric Company. Under Edison's auspices, he worked on a series of electric railroad motors. Finally, in 1893, due to his wife's bad health, he moved his family to California (Secord 1985:8:10).

By September 1893, Ensign had become pipeline inspector for the Mill Creek powerhouse. He quickly advanced in the Redlands Electric Light and Power Company to conduct some of the initial start-up tests for the plant. During the financial panic of 1894, he left Redlands Light and Power to work for the Los Angeles

Figure 16. Wiring Diagram, SAR 1, 1910
(SAR 1 1909-1945)



Railway, where he was in charge of their electrical engineering. By March 1896, Ensign was back with Redlands Electric Light and Power as superintendent of the Mill Creek plant. By the fall of that same year, he had already proposed plans for the Santa Ana No. 1 plant -- plans that called for a 33,000-volt transmission line to Los Angeles. Ensign would later do all of the SAR 1 engineering and transmission line plans (Secord 1985:8.10).

Line Wires and Insulators

Six wires left the Santa Ana powerhouse for Los Angeles. This meant that there were two electrical circuits, each with three wires, one for each of the three impulses picked up off the electromagnets. The wires were No. 1 Brown and Sharpe Gage M.H.D. copper wires; none was coated or covered in any way (Low 1903:30). As an extra precaution against breaking, the wire was "drawn half-hard" (Lighthipe 1899:8).

Despite the length of the wires used in this transmission system, tensile strength of the wire was not nearly as much of a problem as insulation. In fact, the need for insulators that could withstand voltages higher than 10,000 volts was a perennial problem for the electrical industry nationwide throughout the 1890s and early 1900s (Hammond 1941:233). The first patent for an insulator had been issued in 1844, and designs proliferated in response to the needs of the telegraph and then the telephone after 1875. The earliest examples were threadless and failed because the peg separated from the glass. The threaded pin eliminated this problem in the 1860s (Herring 1971:5).

The standard insulator for much of the 1890s was a small porcelain piece made by William Cermak, a Bohemian immigrant potter associated with Edison. The Cermak insulator, however, did not do well with voltages much higher than 10,000 (Hammond 1941:243; Mills 1970:51-53). This limitation led Cermak and other General Electric engineers to experiment with a revolutionary design known as the "petticoated insulator" that had a succession of outflaring ridges (Hammond 1941:243-244). This new design and all its variants would become the standard throughout the early years of the Santa Ana system. During this period, porcelain came to be preferred over glass for higher voltages due to its greater strength (Low 1903:31-32).

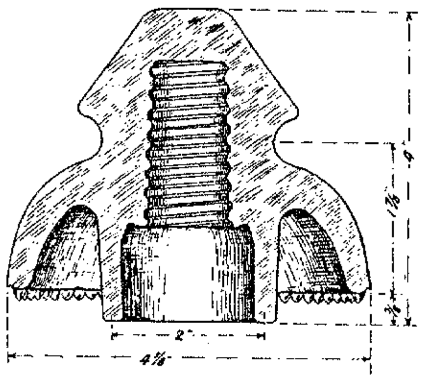
This was the situation when Ensign had to select insulators for the Santa Ana transmission line. He obtained ceramic insulator samples from a representative of the C.S. Knowles Company of Boston for the new 33,000-volt line, but none of the samples held up in preliminary tests (Low 1903:30). On a trip back East to search for better insulators, Ensign finally designed his own model while on a visit to the Locke Insulator Company of Trenton, New Jersey. He actually took a sample in its soft state and carved it into the desired shape with a pocket knife. Ensign's design became known as the "Redlands" type of porcelain insulator, and was the model finally selected for use on the Santa Ana transmission line. It was the first glazed porcelain insulator suitable for high voltage transmission (Low 1903:30; Myers 1986:39; Secord 1985:8.6).

Ensign, assisted by W.H. Workman of Los Angeles, probably completed the models of the new insulators back in California. The prototypes were then sent to C.S. Knowles of Boston, who served as agent and distributor for Imperial Porcelain Works in Trenton, New Jersey (Secord 1985:8:6; Tod 1977:82-87). Ensign stipulated to Knowles that every insulator had to withstand the pressure of a salt water test at 66,000 volts. The successful insulators were white glazed porcelain, around six inches high, with a triple petticoat (Low 1903:30, 39).

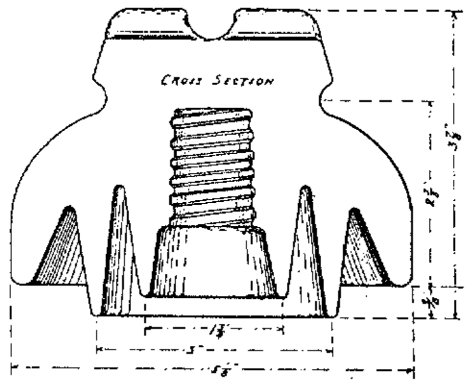
Unfortunately, there has been some confusion as to the name of the insulator Ensign designed for the Santa Ana transmission line. In general, the oldest and most reliable sources maintain that Ensign's insulator was known as the Redlands type. This is sometimes confused with a glass insulator commonly known as the Santa Ana type, which was designed for current of around 10,000 volts. According to the most reliable sources, the transmission line between the Mill Creek plant and Redlands used Santa Ana (glass) insulators, while the transmission line between the Santa Ana plant and Los Angeles used Redlands (ceramic) insulators. More than one researcher has gotten this reversed: Hornbeck and Botts (1988:22) inferred that Ensign designed the Santa Ana insulator; while Secord, after associating Ensign with the Redlands insulator (1985:8.6), also claimed that the SAR 1 insulator was the Santa Ana type (1985:7.10, 12).

The confusion is understandable, because the development of the local insulators was not a simple progression. As reported by F. A. C. Perrine (1903), the first transmission line between the Mill Creek plant and Redlands, which saw service in 1893, used D.G.S.P. Glass Insulators (Figure 17a). When this transmission line was extended to Riverside in 1896 and the current increased to 10,000 volts, porcelain insulators were installed on the line. It would appear that these had no name other than that used in the Low article caption: "porcelain insulators of the Redlands-Riverside transmission" (Figure 17b). Shortly thereafter, the "Santa Ana type glass insulator" was adopted as the standard for 10,000-volt transmission lines, the implication being that it replaced the Redlands-Riverside porcelain insulator in subsequent repairs (Figure 17c).

To complicate matters further, there is a strong possibility that two of the captions on page 55 of the Perrine article were switched and are now attributed to the wrong illustrations. William Myers, historian for Southern California Edison, pointed out that the insulator Perrine identified as "D.G.S.P.," looks like the

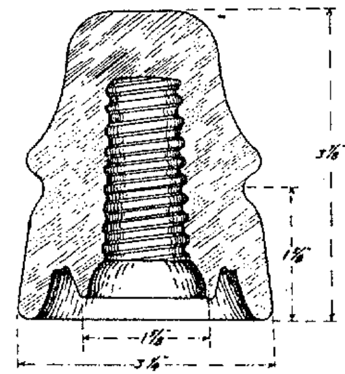


THE D. G. S. P. GLASS INSULATOR ON THE ORIGINAL REDLANDS LINE WHICH AFTERWARD CARRIED 10,000 VOLTS



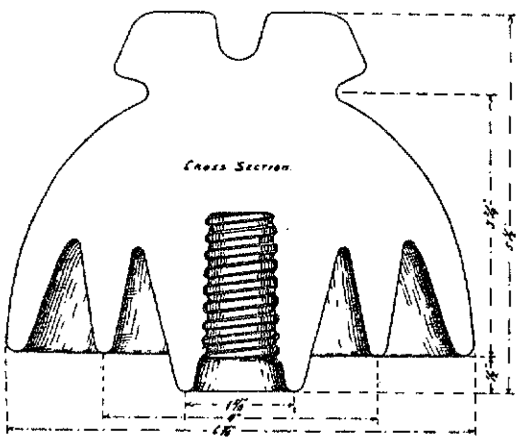
THE EVOLUTION OF A 10,000-VOLT INSULATOR

THE PORCELAIN INSULATOR OF THE REDLANDS-RIVERSIDE TRANSMISSION



THE SANTA ANA TYPE GLASS INSULATOR ADOPTED AS STANDARD FOR 10,000-VOLT WORK

Figure 17. 10,000-Volt Insulators
(Perrine 1903:55)



THE REDLANDS TYPE IMPERIAL PORCELAIN INSULATOR

Figure 18. Redlands Type Imperial Porcelain Insulator
(Low 1903:41)

Santa Ana type glass insulator currently on display in the history museum of Southern California Edison at the corporate headquarters in Rosemead. The author examined this insulator in October 1992 and found this to be so.

An inadvertent caption switch does make sense. Figure 17c is a more primitive-looking insulator, while the flared-base of Figure 17a is a trait associated with higher voltage insulators. In all probability, Figure 17a is the Santa Ana type glass insulator, while Figure 17c is the earlier D.G.S.P. type. This is further corroborated by the illustration of a Santa Ana type glass insulator in a 1902 catalogue (C.S. Knowles 1902: Figure 19). This Santa Ana insulator looks like Figure 17a, not Figure 17c.

Mercifully, the insulator designed by Ensign was different from all of these, and was formally known as the "Redlands Type Imperial Porcelain Insulator" (Figure 18). This type of white ceramic insulator was made at the Imperial Porcelain Works in Trenton, New Jersey (Low 1903:30; Tod 1977:82-87). The Redlands insulator was only a variation of the Imperial High Potential Porcelain Insulators that Knowles had been popularizing for the Imperial Porcelain Works since at least 1897. At that time, Imperial High Potential Porcelain insulators were already in use on the famous Niagara-Buffalo transmission line, and were planned for the 33,000-volt Santa Ana transmission line (*Journal of Electricity* 1897:27; Figure 20).

Transmission Line and Wire Transposition

When Ensign received the new Redlands porcelain insulators, he tested them with current from a special 10 kw transformer that generated 70,000 volts before installing them on the transmission line poles (Lighthipe 1899:9; Low 1903:30). Even though the new insulators passed the test, the high voltage of the line created additional problems that had never before been encountered. The most serious of these was the unwanted electrical field set up by the powerful current in the three wires of each of the two circuits. To understand this phenomenon, the position of the wires has to be explained.

Each transmission line pole had two cross arms (Figure 21). The top cross arm was 5 feet 1 inch long; the bottom was 6 feet 8 inches, with additional braces to secure it to the pole. The upper cross arm held two insulators; the longer lower arm had four. The insulators had been made with screw mounts so they could be affixed to wooden pins set into the cross arms. The three wires of one circuit were positioned on one side of the pole, occupying one half of the upper and lower cross arms; the other circuit occupied a similar position on the other side of the pole. Seen in cross section, the three wires of each circuit were arranged on the

Figure 19. Generic Imperial Insulator ca. 1897
(*Journal of Electricity* 1897:27)

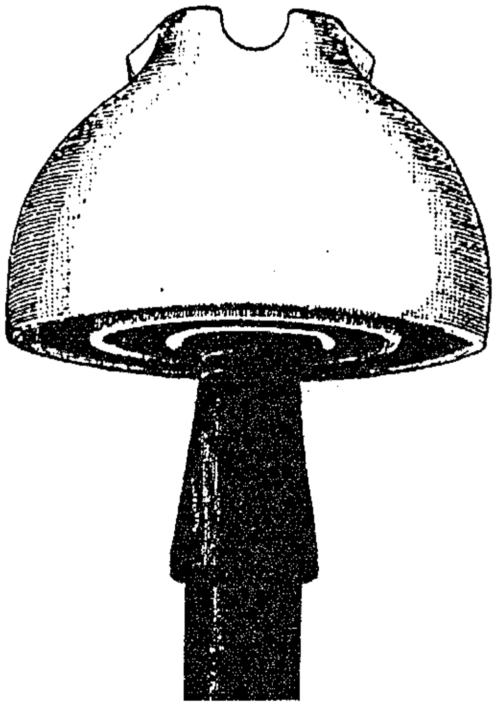
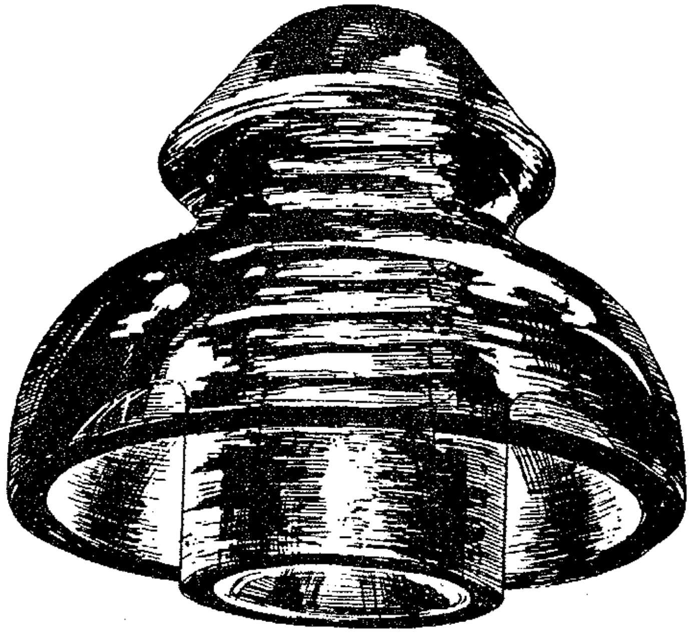


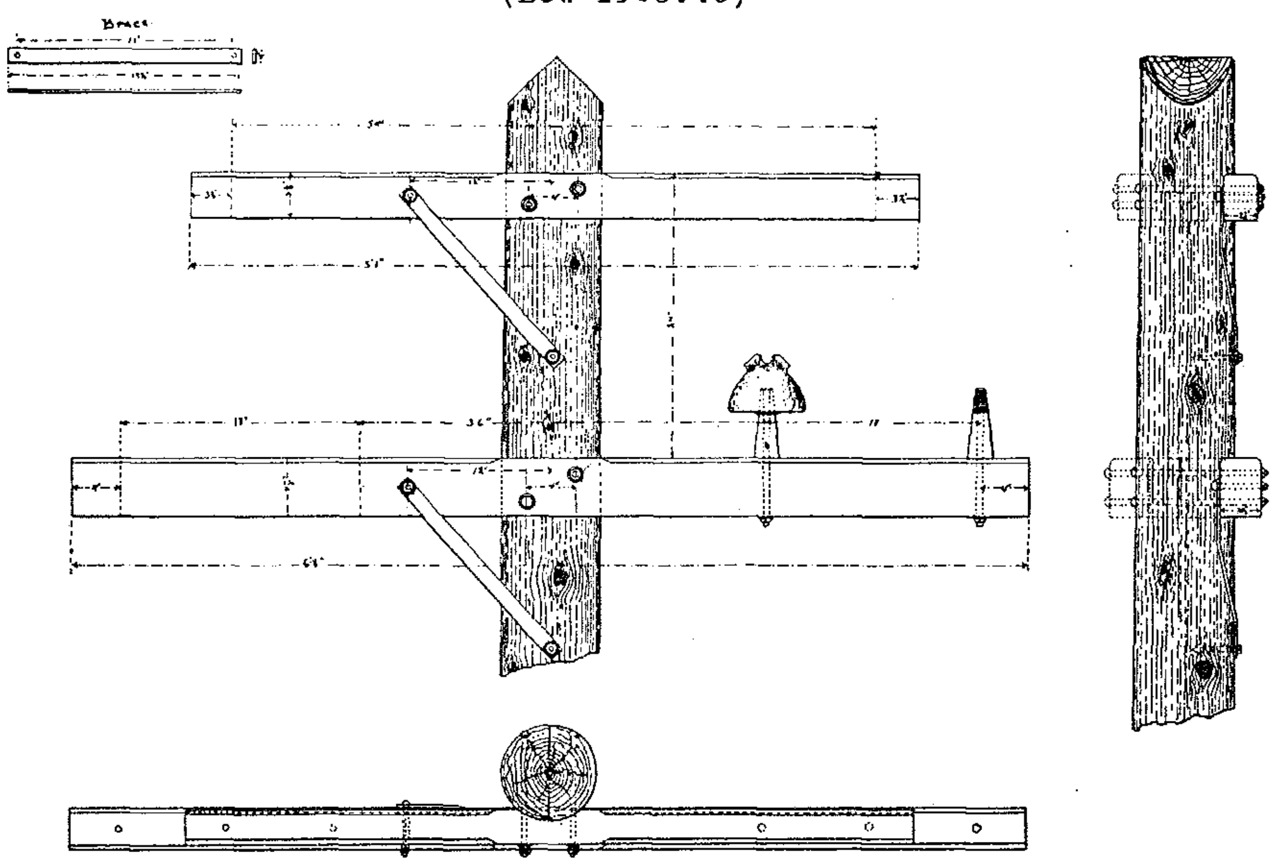
Figure 20. Santa Ana Glass Insulator
(Knowles 1902)



transmission poles in the pattern of an isosceles triangle. The triangle formed by the wires was 28 inches on two sides, 17 inches on the third (Lighthipe 1899:9; Fowler 1899:149; Low 1903:30).

When this transmission line was first put up and tested, it was found that the 33,000-volt current traveling in an unbroken pattern created an electromagnetic field around the wires. This caused static noise in the vicinity of phone lines, and created particular problems for the critical two-wire telephone line that was installed on the transmission line poles just five feet below the lower cross arms (Fowler 1899:149; Lighthipe 1899:9). Unless the problem could be resolved, telephone communication between Los Angeles and the Santa Ana plant would not be possible.

Figure 21. Santa Ana Pole Line
(Low 1903:40)

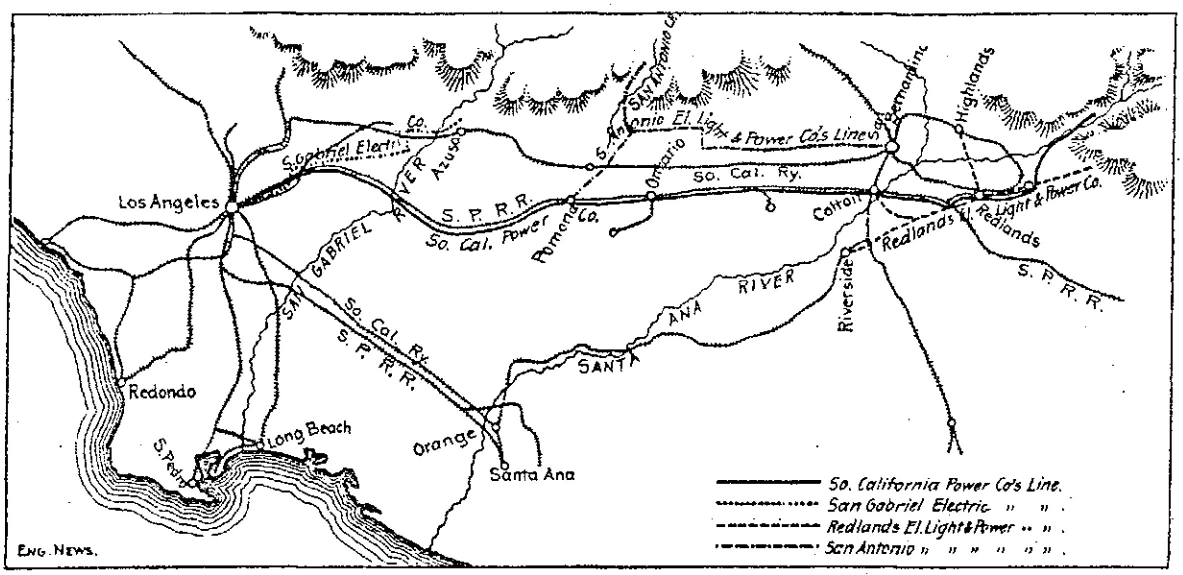


ARRANGEMENT OF INSULATORS AND CROSS-ARMS ON THE 33,000-VOLT POLE LINE OF SANTA ANA-LOS ANGELES TRANSMISSION

The solution was found to be transposing the wires along the transmission line. The three wires of the north circuit were spiraled one-third of a rotation every 41 poles; the three wires of the south circuit were spiraled in a similar fashion but in the opposite direction every 88 poles. The spiraling was arranged so that the two circuits were never transposed on the same pole. Even the two telephone wires were transposed, one over the other, every five poles (Lighthipe 1899:9; Fowler 1899:149).

The spacing of the poles was also carefully arranged. In the rugged Santa Ana Canyon, poles were 30 feet high, set 110 feet apart, for a distance of at least 5.5 miles. From Crafton to Los Angeles, where the line followed the Southern Pacific Railroad right-of-way (Figure 22), the poles were 35 feet high and spaced 120 feet apart. When the line went through towns, the poles were 50 feet high (Lighthipe 1899:8). The poles were all white cedar, with an 8-inch diameter at the top (Fowler 1899:149). The tops of the poles were beveled to shed water and help prevent rot.

Figure 22. Transmission Lines in Southern California
(Fowler 1899:146)



Plant Start-Up and Initial Problems

By almost all accounts, the Santa Ana Canyon plant, now known as Santa Ana River Powerhouse No. 1, was ready for operation by December 1898; it was then that water was first diverted into the conduit system and the generators started up (Low 1903:13; Pearson 1912d:15; Fowler 1923:591; Secord 1985:8.7).

Almost immediately, it was apparent that something was wrong. When the line voltage was raised to 16,000 volts, the lightning arresters started to arc just outside the powerhouse and had to be separated farther apart. At 18,000 volts, instruments at both ends of the 83-mile transmission line indicated that the current was "shorting" to ground somewhere along the line. Even though the plant was shut down and the whole line examined, no problems could be observed. It was then decided to start the plant at night in hopes that the energy loss could be spotted against the darkness. That first night, the problem was discovered in the vicinity of Ontario, where two wires had been transposed incorrectly and were only one inch apart, causing a great electrical arc up and down the line (Lighthipe 1899:13; Low 1903:32).

After this situation was corrected, the transmission line presented no further problems. A short in one of the fuses caused a pyrotechnic display inside the powerhouse (Pearson 1912d:16), but after this, the whole system was ready to go on line. According to one source, who had access to powerhouse logs that no longer exist, Unit 3 went on line first, on 9 January 1899. Unit 4 was initiated the following day. Unit 2 followed one month later, on 10 February, while Unit 1 went into operation on 14 February 1899 (Nimmo 1945; Myers, personal communication 1992). At that time, SAR 1 had the longest and most powerful commercial transmission line in the United States (Hinson 1956:22).

In 1899, most of the power generated at the Santa Ana plant traveled 83 miles to Edison Electric Company's Second Street station in Los Angeles. There, six General Electric 250 kw transformers stepped the voltage down from 33,000 to 2200 volts. Some of the current was then carried to Edison's new Fourth Street station, where it ran a 300 kw General Electric synchronous motor that used 2200-volt current. The rest of the power went out from the Second Street station to homes and businesses for lighting use. This power was carried at 2200 volts and then stepped down to 110 and 220 volts by small transformers at each house (Fowler 1899:149). Before the main transmission line even reached the Second Street station, an auxiliary line carrying 33,000 volts went to Pasadena, where it was reduced by transformers to 2200 volts and used to power the cable car line to Echo Mountain (Lighthipe 1899:11).

By the time Low wrote his 1903 article, the SAR 1 system had been in continuous operation for four years. All repairs to the powerhouse had been minor: valve and small pipe replacements, nozzle tip replacements, and the replacement of a few of the exciter water wheel buckets. Low was careful to point out that not a single bucket on any of the large Pelton wheels had been changed. The most serious problem to plague the system concerned the vulnerable transmission line. Rain caused some voltage leakage, but the worst was fog, which could create a form of leakage that showed up at night as luminous spots on the line (Low 1903:29,31).

In 1903, the powerhouse was still such a novelty that visiting dignitaries were treated to special trips down the flumes and tunnels of the conduit system. Low himself took such a trip in a small boat, beginning at the sandbox between Tunnels 3 and 4 and ending at the opening of the last tunnel. It had taken workmen all day to push the boat up to the intake; Low's 2.5 mile tour downstream took all of 20 minutes (Low 1903:16-18).

Other Famous Santa Ana Plant Personnel

The construction and operation of the Santa Ana plant made a number of reputations. Perhaps the most famous was Orville Ensign, the chief electrical engineer who was closely associated with the development of SAR 1, particularly its transmission line. Ensign served as Edison's "Chief of Electrical and Mechanical Engineering" until 1904. At that time, he became chief electrical and mechanical engineer for the U.S. Reclamation Service, a post he filled until 1915 (Secord 1985:8:11). Ensign passed away in 1935.

There were others that made their reputations at SAR 1. James A. Lighthipe, who wrote one of the first articles on the powerhouse in 1899, was at that time an engineer for the General Electric Company's Pacific Coast District. In the early 1900s, he worked for Edison as a consultant in the development of the Kern River transmission line. Around 1908, Lighthipe made the move to Edison Electric as chief engineer and was put in charge of the generator equipment and much of the switching equipment. According to one source, Lighthipe designed the Lombard governing equipment used on water wheels at SAR 1 and later, SAR 2 (Secord 1985:8.11). He was later instrumental in the design of the huge 220,000-volt line between Big Creek and Los Angeles.

In his 1899 article, Lighthipe credited others who contributed to SAR 1. Edward M. Boggs was the chief civil and hydraulic engineer. He was apparently associated with M.L. Loon (Secord 1985:8.11). H.H. Sinclair, head of the Southern California Power Company, was responsible for some of the plant's conception and most of its construction organization. Other people mentioned in connection with the powerhouse were H.C. Thaxter, superintendent of the Edison Electrical Company; George H. Barker, president of the company; and John B. Miller, treasurer (Lighthipe 1899:13).

Still others would be important later. The most prominent in this category were probably A.W. Butterfield, plant supervisor, and Benjamin F. Pearson, who would eventually rise to become general superintendent of the Southern California Edison Company. Pearson was born in 1868 in England, where he first worked as a planer and lathe man before joining the Grand Junction Canal Company. He moved to California in 1896 and was soon employed by Edison. One of his first jobs was brush cutter with the survey crew that laid out the tunnels and flumes for SAR 1. For this work, he received $2 a day (*Edison Current Topics* 1912e)

Pearson soon advanced from brush cutter to chain man, even doing time as a "mucker," one of the underground workers assigned to the SAR 1 tunnels. Pearson performed many different tasks while at SAR 1, working as a machine man on the Burley drill equipment and the air compressors. When the plant went on line, he served as dynamo tender and switchboard man, and finally rose to become supervisor of the plant before being called to another position in Los Angeles (*Edison Current Topics* 1912e). His place at SAR 1 was later filled by Butterfield, who served in the canyon for many years around the 1920s.

Major Support Structures at SAR 1

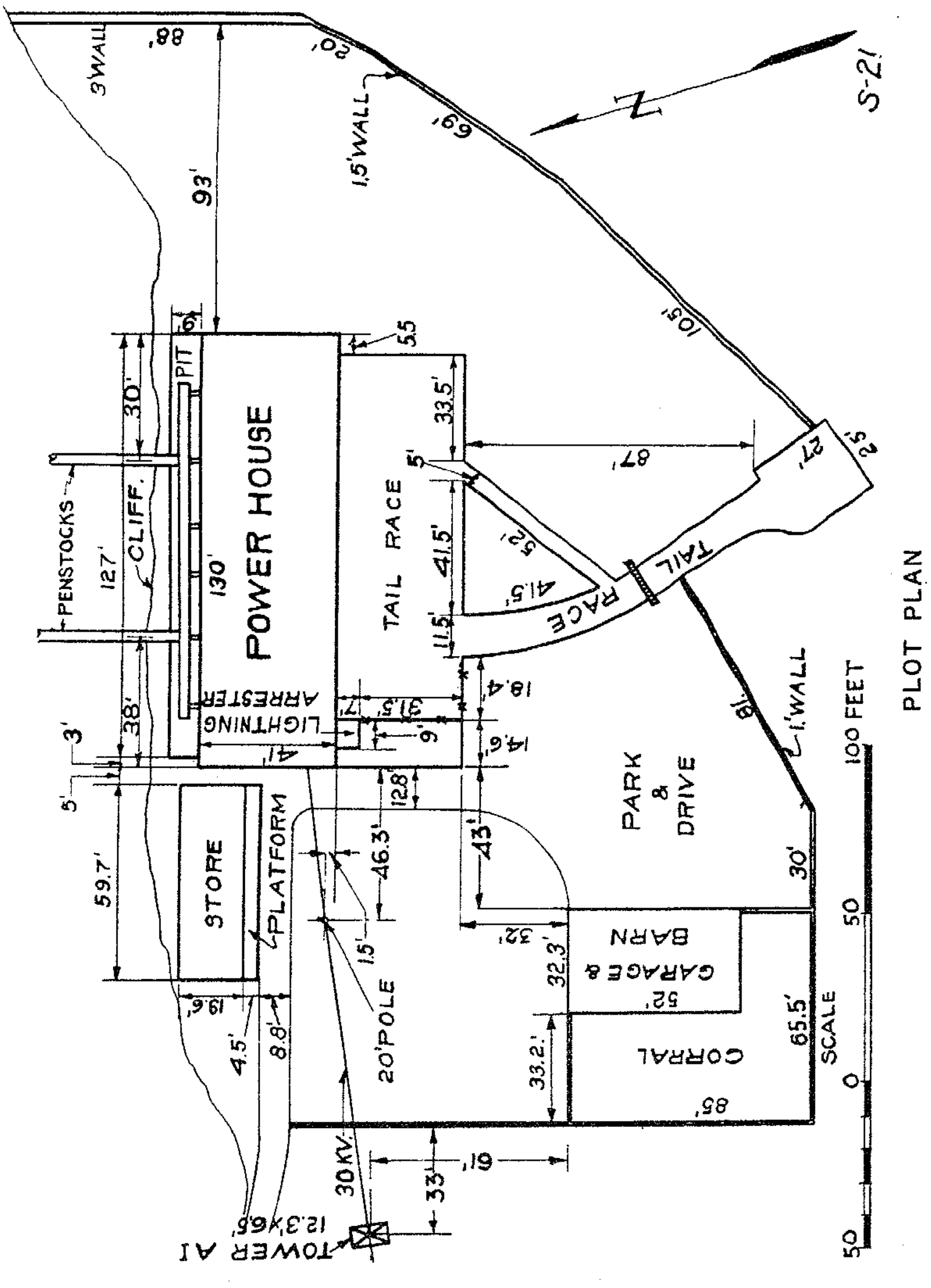
From the very beginning of the Santa Ana plant, a complex of auxiliary structures adjacent to the powerhouse provided the support system needed to keep the powerhouse in operation. The earliest of these structures, including worker housing, no longer exist. The present configuration of auxiliary buildings, such as the current machine shop, storage shed, and barn, were constructed in 1912 (Figure 23).

The 1912 machine shop and storage shed occupied a building located immediately west of the powerhouse. It measured 19.6 x 59.7 feet and was a single story concrete structure. The roof was a single-gable wood frame with a corrugated metal cover (Secord 1985:7.7).

The original plan of the machine shop, dating to 1912, depicts the building as divided into four separate compartments. From east to west, they were the blacksmith shop, store room, paint room, and oil room -- the latter with three oil tanks and filters (Drawing 4673; CA-130-L-6). At present, the first compartment, now commonly identified as the machine shop, contains an old lathe, drill press, and furnace, with much equipment formerly belt-driven off an electric motor. At the turn of the century, much of this equipment was located in the powerhouse itself, situated in the area where Units 5 and 6 would have been if they had been installed. The machine shop was in use until shortly after World War II (Secord 1985:7.10). In what is now the switchrack yard south of the machine shop, there is an old horse-drawn road grader believed to have been used during the original construction of the canyon road to the powerhouse and later used in road repairs (Secord 1985:7.10).

The most impressive of the major support structures is the barn, identified in 1912 as a stable. The stable was a two-story rectangular unreinforced concrete building with a single gable corrugated iron roof. In plan, the stable measured 32.3 x 52 feet, with its main axis perpendicular to the powerhouse, which is 70 feet away to the northeast. Ground floor access was provided by five doors on the east side, each measuring 7.5 x 8 feet. Six stalls were located along the west wall. The second floor was originally used as a hay-loft, with a second story entrance located above the middle of the five doors on the ground floor (Secord 1985:7.7). The original 1912 plan depicts five stalls, a wagon room, a burro room, and a harness room; the upstairs was identified

Figure 23. Plan of SAR 1
(SAR 1 1909-1945)



Placed in Operation 1898.

41'x130' Concrete Building, Corrugated Iron Roof, Cement Floor.

as a grain bin (Drawing 4674; CA-130-K-13). Associated with the stable was a corral, located immediately to the west.

Most other auxiliary structures associated with SAR 1 were more temporary and do not now exist. An exception was the original powder magazine, which was surprisingly small. This could be construed as indirect confirmation that most of the SAR 1 tunnel work was done by drill rather than blasting.

Also associated with the powerhouse were the living quarters of the staff, situated on the terraces immediately above the powerhouse on the northeast side. Although all of these buildings are now gone, there was at one time a number of residences, bunkhouses, and a boardinghouse located on these terraces. These buildings and the people who lived in them once comprised a vital component of the Santa Ana community that saw its zenith in the 1910s. The story of this community is presented after the discussion of the other two powerhouses, in Chapter 8.

Impact of SAR 1 and Subsequent Development of the Edison Electric Company

The Santa Ana plant, later referred to as Santa Ana River No. 1 or SAR 1, represented a number of firsts for the commercial electrical industry and the Edison Electrical Company. SAR 1 was the first plant to be constructed by Edison, even though technically it was begun by one of its subsidiary companies, a common procedure used by Edison in the early days (Myers, personal communication 1992); all earlier plants had been obtained by purchase or merger. SAR 1 had the world's largest generators at the time of installation, and was the first to use individual tail races in the lay-out of the powerhouse. At 83 miles, it had the longest commercial transmission line in the United States, if not the world. The Santa Ana plant had one of the highest voltages ever transmitted, 33,000 volts, and was the first to transpose wires to eliminate unwanted electromagnetic fields along the transmission line (Fryer 1980:16; Secord 1985).

The Santa Ana plant became the standard for hydroelectric powerhouses in southern California, and paved the way for larger hydroelectric plants even farther away. The Santa Ana plant proved once and for all the efficacy of hydroelectric power in California, where coal was too expensive and local oil had not yet become a cost-effective fuel. SAR 1 also showed that large electrical companies were the model of the future, and were essential to secure the kind of investors and financial resources needed to see large powerhouse construction to completion (Myers 1991b:43-46; 87-88).

The advantage of company growth was clearly seen by John Barnes Miller, who became president of the Edison Electric Company in 1901. The success of SAR 1 helped convince Miller that Edison had to establish a more secure financial base by combining with other local utility companies. He pursued this goal with a zeal that made him known as "The Great Amalgamator." With this enhanced financial base, he also advocated the construction of new hydroelectric powerhouses, specifically SAR 2 and the much larger Kern River plant (Myers 1986:41-43).

The need to regroup after so many acquisitions led Miller to reorganize the Edison Electric Company in 1902. For tax purposes, the Edison Electric Company became a Wyoming corporation, with capitalization of $10 million and an authorized bond issue for another $10 million (Second 1985:8.5,8). Under Miller, the Edison Electric Company went from success to success. The Santa Ana plant was soon overshadowed by larger powerhouses with even longer transmission lines, beginning with the first powerhouse constructed on the Kern River at the southern end of the Sierra Nevada.

Before the first Kern River plant was put into operation, however, the Edison Electric Company went back to Mill Creek and the Santa Ana River, and developed the hydroelectric potential of those two streams to the maximum then possible. Even before SAR 1 was put on line, construction had already begun on the Mill Creek No. 2 plant, just above the intake of the first Mill Creek plant.

Mill Creek No. 2 was completed in one year, with construction beginning in October 1898; the plant went on line in November 1899, about nine months after SAR 1. Like those at SAR 1, the generators were the revolving field type, with the electromagnets turning on the rotor and the windings on the stationary stator. The Mill Creek No. 2 generators were unique, however, in that they were wound to generate 10,000 volts directly, so that no step-up transformers were required to boost the current. This current was then fed directly into the pre-existing Mill Creek current distribution system, already set for 10,000 volts. The Mill Creek No. 2 generators were the highest voltage machines in the entire Edison system for the next eight years (Low 1903:12-13; Pearson 1912d:16; Hinson 1956:24).

By this time, the Edison Electric Company had a total generating capacity of more than 5000 kilowatts, 96 percent hydroelectric. The main Edison plants then in operation were SAR 1, Mill Creek 1 and 2, Los Angeles No. 1, and a steam plant on Vermont Avenue (Dennis 1913:3; Myers 1991b:84). The centerpiece of the Edison system, and, at 3000 kw, its greatest producer, was still the Santa Ana plant.

Mill Creek No. 3 was essentially an extension of Mill Creek No. 2, and was begun soon after the latter went on line. To make room for Mill Creek 3, the No. 2 powerhouse was enlarged and the new pressure pipe was made 8400 feet long. Mill Creek 3 went on line in early 1903. The head of water for the new plant was 1960 feet, with a static head of 1911 feet. For years, this was the highest head of pressure in the United States, to be exceeded only in 1913 by Big Creek No. 1, with a static head of 2131 feet (Low 1903:13; Pearson 1912d:16; Hinson 1956:28).

6. SANTA ANA RIVER NO. 2

On the Santa Ana River, the success of SAR 1 led to the construction of Santa Ana River No. 2 (SAR 2) immediately below it (Pearson 1912d:16). After years of delay, SAR 2 was finally put on line in May 1905 with two 500 kw generators. After the current was stepped up to 33,000 volts by transformers, it was then connected to the existing 33,000-volt line between SAR 1 and the Colton substation (SAR 2, 1909-1945; Hinson 1956:38).

It is clear from the existing records that SAR 2 was conceived almost as early as SAR 1. In 1897, Letter "F" from the General Land Office Commissioner advised the Register and Receiver in Los Angeles that the Secretary of the Interior had approved a right of way application filed by A.G. Hubbard for the development of a hydroelectric plant below SAR 1. This became known as the "Hubbard Power Right," which was a 20-acre set-aside for a powerhouse intake and another 20 for the powerhouse itself. These two areas were duly surveyed in January 1897. From all indications, Hubbard did little with this right, which he eventually relinquished to the Mountain Power Company in 1900 (Foster et al. 1989:10-11).

Mountain Power Company had been incorporated on 27 March 1900 for the express purpose of developing a second powerhouse on the Santa Ana River. The company was a wholly-owned subsidiary of Edison Electric (Secord 1985:8.6). Orville Ensign, a prime mover on SAR 1, did some of the engineering plans for SAR 2 before he left Edison's employ in 1904 (Secord 1985:8.10). Construction of SAR 2 began under the auspices of Mountain Power in 1902, but the company was dissolved that same year and its assets absorbed directly into the Edison Electric Company. With the exception of some tunnel work, virtually nothing had been done by the time of Mountain Power's demise. Construction did not begin again in earnest until mid-1904, with the work completed in May 1905, one year later (Secord 1985:6.7, 7.7, 8:8; Foster et al. 1989:11).

According to Edison's records, the powerhouse building itself was completed on 15 April 1905 (SAR 2, 1909-1945). Unit 2 was the first to be put on line, on 20 May 1905. Unit 1 was running and ready on 5 June, but was not put on line until the 7th (Nimmo 1945).

Unfortunately, much less is known about the construction and early condition of SAR 2 than about SAR 1. SAR 2 did not make engineering history, and it would appear that no commemorative articles heralded its inauguration. As was the case with SAR 1, most of the earliest Edison records of the SAR 2 operation have not been preserved. With the exception of Edison's internal accounting of the powerhouse operation, dating no earlier than 1909 (SAR 2, 1909-1945) and a few modern Edison engineering drawings traced from older plans now lost, the earliest reliable account of SAR 2 was provided by Frederick Fowler in his 1923 study of hydroelectric generation in California. What is known about the early lay-out of SAR 2 is presented here in the order established for SAR 1: intake, conduit system, powerhouse lay-out, water wheels, generators, and other elements of the electrical system.

Intake and Conduit System

The intake of SAR 2 began at the tailrace of SAR 1. After water from the four SAR 1 tailraces joined in a common channel, it passed to a concrete-lined inlet chamber adjacent to the river bank that measured 25 feet square and 5 feet 7.25 inches deep. From this point, the water was conveyed to the SAR 2 main conduit line by way of a 40-inch diameter steel siphon that was 433 feet long and passed under the river bed to the opposite or southeast side of the canyon. The siphon joined the main conduit at the sandbox below Tunnel 1. Tunnel 1 headed onto the river opposite the SAR 1 powerhouse, and was designed to be used only as an emergency intake if water ever had to be taken directly from the stream (Fowler 1923:594).

At present, this intake system is augmented by water from three additional sources: the Santa Ana River adjacent to the SAR 1 powerhouse (not the same as the intake at SAR 2's Tunnel 1); Alder Creek; and Keller Creek. At least two of these date to the earliest days of SAR 2. As Fowler makes clear, the original SAR 2 intake system had siphon intakes on both Alder and Keller Creeks (no mention is made of the intake directly from the Santa Ana River). These two small siphons were 10-inch diameter pipes. The pipe from Keller Creek was 895 feet long; from Alder Creek, 857 feet long (Fowler 1923:594-595).

Both the Alder and Keller Creek siphon intakes were flooded out by 1911. In 1919, Keller Creek got a new intake, with water carried by an 8-inch galvanized pipe gravity line some 1170 feet long that emptied into the tailrace of SAR 1. In 1923, the Alder Creek intake had still not been repaired (Fowler 1923:590).

At present, the Keller Creek gravity pipe dumps water into one of the tailraces underneath the SAR 1 powerhouse so that it can be picked up by the SAR 2 conduit system. The Alder Creek intake has been repaired and has its own fish screen and leaf rake. Water is conveyed through a gravity pipeline across the Santa Ana River to the SAR 2 conduit system. Additional waters are also diverted from the Santa Ana River immediately east of the SAR 1 powerhouse via an earthen dam and grated gate. Before this water enters the SAR 1 tailrace, it passes through an unusual sandbox known as a "round file" (Hamilton, personal communication 1992). The Santa Ana River intake may have been added to the system when the Alder Creek intake was finally repaired.

The main sandbox on the SAR 2 conduit was described in 1923 as 30 feet long and 9 feet wide, with two hoppers. The bases of the hoppers sloped toward each other, with depths varying from 4 feet to 8.5 feet (Fowler 1923:594).

The conduit itself, without the two small feeders from Keller and Alder, was 8560 feet long from the tailraces of SAR 1 to the forebay of SAR 2. This included the 433-foot long, 40-inch diameter siphon that crossed the river just below SAR 1, and another siphon, 44 inches in diameter, that was 201 feet long. There were a total of 12 tunnels with a total length listed as either 7571 or 7734 feet. There were either one or two flumes, depending on the source, for a total of 265 or 486 feet. Most of the tunnels were connected, not by flumes, but by inverted metal syphons buried into the mountain side. The average grade of this conduit system was a drop of 7.92 feet per mile (Fowler 1923:595; SAR 2, 1909-1945).

The vast majority of the SAR 2 conduit system was comprised of tunnels. They were completely concrete-lined, except for a 1120-foot section where the arch portion was not faced. This section was lined only on the floor and along the walls. The width of all the tunnels was 4.5 feet. The concrete-lined tunnels were 6.5 feet high from the floor to the peak of the arch. The waterway channels themselves were 4 feet deep, with a carrying capacity of 100 second feet (Fowler 1923:595; Drawing 5110869).

The SAR 2 forebay was a small concrete box equipped with sluice gates to help flush any sediments that might accumulate. In 1923, a wooden box waste flume ran down the side of the canyon from the forebay into the SAR 2 tailrace just outside the powerhouse (Fowler 1923:595).

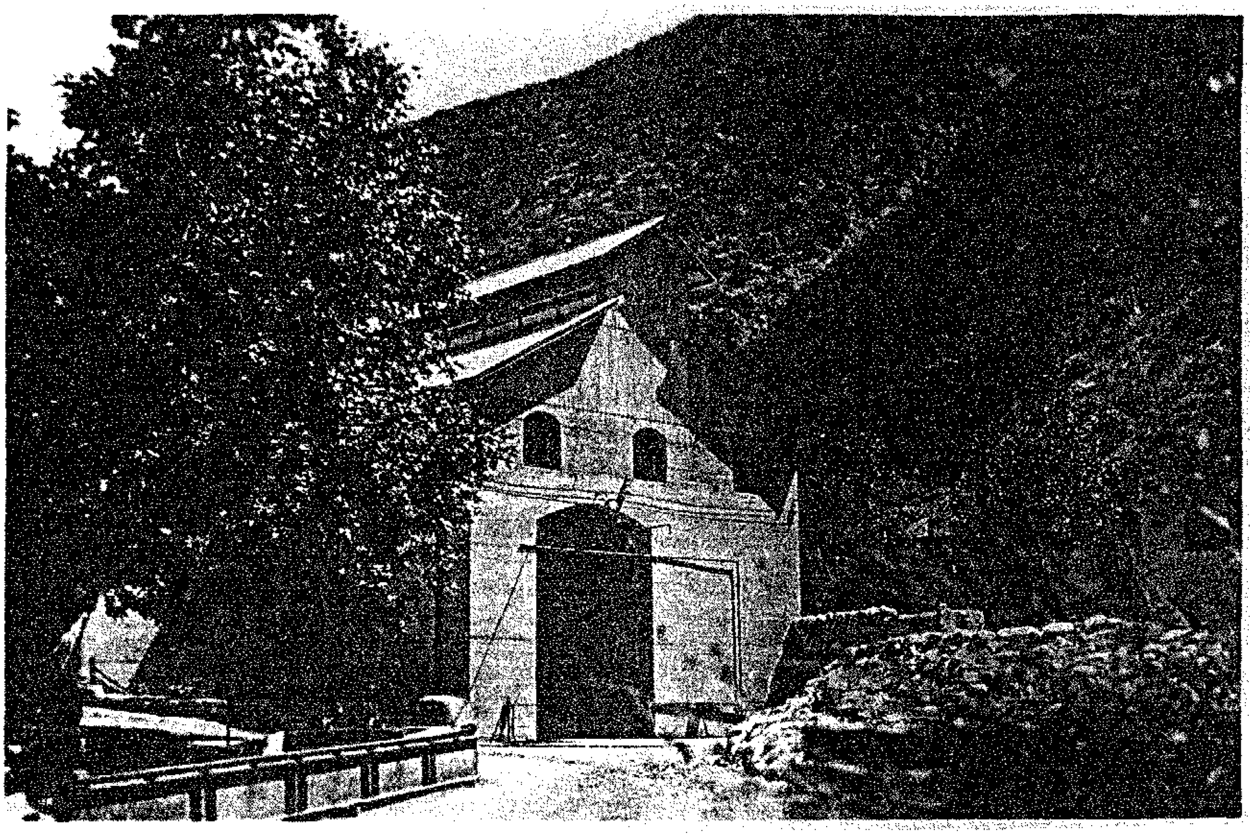
The penstock or pressure pipe, as it was still called in 1923, had a diameter of 36 inches and was either 644 or 647 feet long, depending on the source. The pressure pipe was single lap riveted and buried into the side of the canyon. SAR 2 had an excellent siting as far as the pressure pipe was concerned: it was a straight shot into the powerhouse. The static head was listed as 305 feet (Fowler 1923:595; SAR 2, 1909-1945).

At the powerhouse, the base of the pressure pipe had a 36-inch diameter gate, beyond which the pipe bifurcated into a "Y," with each branch having a diameter of 20 inches. The "Y" branches turned the water at right angles in opposite directions. By this point, the pipes are underneath the cliff-facing wall of the powerhouse and aimed at the two water wheels. Additional gate valves were located in each branch of the "Y" underneath the powerhouse (Fowler 1923:595; SAR 2, 1909-1945). Today, these gate valves are known as "TSOs," or turbine shut-offs (Hamilton, personal communication 1992). The nozzle through which the water was aimed had a 7.25 inch bore, with a stream diameter of 6.3 inches (SAR 2, 1909-1945).

Powerhouse Plant

According to the earliest known plans, dating to 1904, the powerhouse was to be rectangular, with a smaller rectangular bay added to the west side (Drawing 5392). Fowler described the powerhouse as a concrete structure, with a corrugated galvanized roof supported by steel trusses (Figure 24). The main building was 33 feet 3 inches wide by 64 feet 3 inches long, with the main axis oriented roughly north-south. The bay on the west side was 24 feet 8 inches by 15 feet 2 inches (CA-130-Q-40). In 1923, the switchboard and most of the wiring were located in or adjacent to this bay (Fowler 1923:595). There were also five windows on the east or penstock side, three windows each on the north and south sides, and four windows on the west side. Six glazed tile pipes were installed in the west wall of the building (Drawing 5392).

Figure 24. SAR 2 Powerhouse, 1909
(Finkle 1910:47)



The main entrance to the powerhouse was a 12 x 18-foot door on the south side (Secord 1985:7.7). The generators and water wheels were lifted into place and serviced with a five-ton crane and chain hoist (Secord 1985:7.11). Another critical feature of SAR 2 was the noise-insulated phone booth with its magneto-operated telephone, which allowed communication with the other local powerhouses and Los Angeles. As late as 1985, this telephone was still in operation (Secord 1985:7.8).

In the 1910s, the powerhouse was surrounded by a number of other structures that were required to house people and equipment in the days before automation and automobiles (CA-130-42). In addition to the powerhouse, there were four cottages, each roughly 24 x 38 feet, one stable and wagon shed (12 x 50 feet), one machine shop (12 x 30 feet), one storeroom (11 x 20 feet), and a bunkhouse of 16 x 28 feet (SAR 2, 1909-1945; Foster et al. 1989).

Water Wheels

Unlike SAR 1, which had four generating units and was actually designed for six, SAR 2 was not designed for more than two. According to the earliest known plans, dated to 1904, it was always assumed that the water wheels of these units would be Doble wheels, rated at 800 horsepower, with cut-out double buckets (Drawing 4611). These Doble wheels were installed in April 1905. Each wheel had 18 buckets, giving the wheel centerline a diameter of 84 inches. The wheels were capable of 176 revolutions per minute (SAR 2, 1909-1945; Fowler 1923:595-596). Wheel efficiency was rated at 80 percent (SAR 2, 1909-1945).

As at SAR 1, the two wheels of SAR 2 were each direct-connected to a generator via a three-bearing shaft supported by cast iron bed plates. The nozzle aimed at each of the wheels was controlled by a Type F Lombard governor. Both units could be shut off by the hand-operated gate valves located in the "Y" branch pipes just inside the powerhouse (Fowler 1923:595-596). The Lombard governor has since been replaced by a Woodward water wheel governor, Type LR, made by the Woodward Governor Company of Rockford, Illinois. In early 1992, the Woodward governors were still in use at SAR 2. The original Lombard governors were almost surely manually operated. By 1923, the powerhouse was already under semi-automatic control, which regulated the water level in the forebay and was capable of taking the generator off line in case of a short circuit (Fowler 1923:596). From all indications, semi-automatic control meant that the machinery still had to be started manually, but would thereafter regulate itself.

The lay-out and orientation of the two water wheels at SAR 2 are quite different from the design at SAR 1. At SAR 1, there were four wheels, all parallel to the penstock, each powered by water that had to go through the pressure pipe, the receiver, and then the outlet pipes and nozzles. In most cases, the water had to make two hard right-angle turns. At SAR 2, the water made just one curved right-angle turn in the "Y" branches to power two wheels that were set perpendicular to the penstock (CA-130-Q-43).

There are a number of possible reasons for this change. Perhaps the number of right angles between the pressure pipe, receiver, and outlets of SAR 1 created more friction than the published literature suggested, and the "Y" branches were designed to counter this problem. Alternatively, perhaps the real reason for the orientation was that there was simply no need for a receiver: there could never have been more than two units at SAR 2. This was based on the SAR 2 location, which was predetermined by the prior existence of SAR 1 and the intake of the Santa Ana Canal. SAR 2 had to be planned around existing water rights in the canyon, and the water that SAR 2 took from SAR 1 had to be returned to the river at or before the Santa Ana Canal intake. Thus, SAR 2 could not be located farther down the canyon where it would develop a higher head of water pressure. Unlike SAR 1, which had 700-plus feet of pressure in the penstock, SAR 2 could not have more than about 300 feet because that was all that was available at the intake of the Santa Ana Canal. Even the grade of the conduit was made shallower than any other line in the system, 7.92 feet per mile, in an attempt to increase the powerhouse head.

Generators and Exciters

The generators, which were direct-connected to the water wheels, were located on the west side of each wheel. They were General Electric Class 34-500-176, made in Schenectady, New York, each with a rated capacity of 500 kw. Each had a 34-pole revolving field that could produce 750 volt current that was three-phase and 50 cycle. The generators, like the water wheels, operated at a speed of 176 revolutions per minute. They were installed around April of 1905 (SAR 2, 1909-1945; Fowler 1923:596). Even in the early days, generator efficiency was rated at 95 percent (SAR 2, 1909-1945).

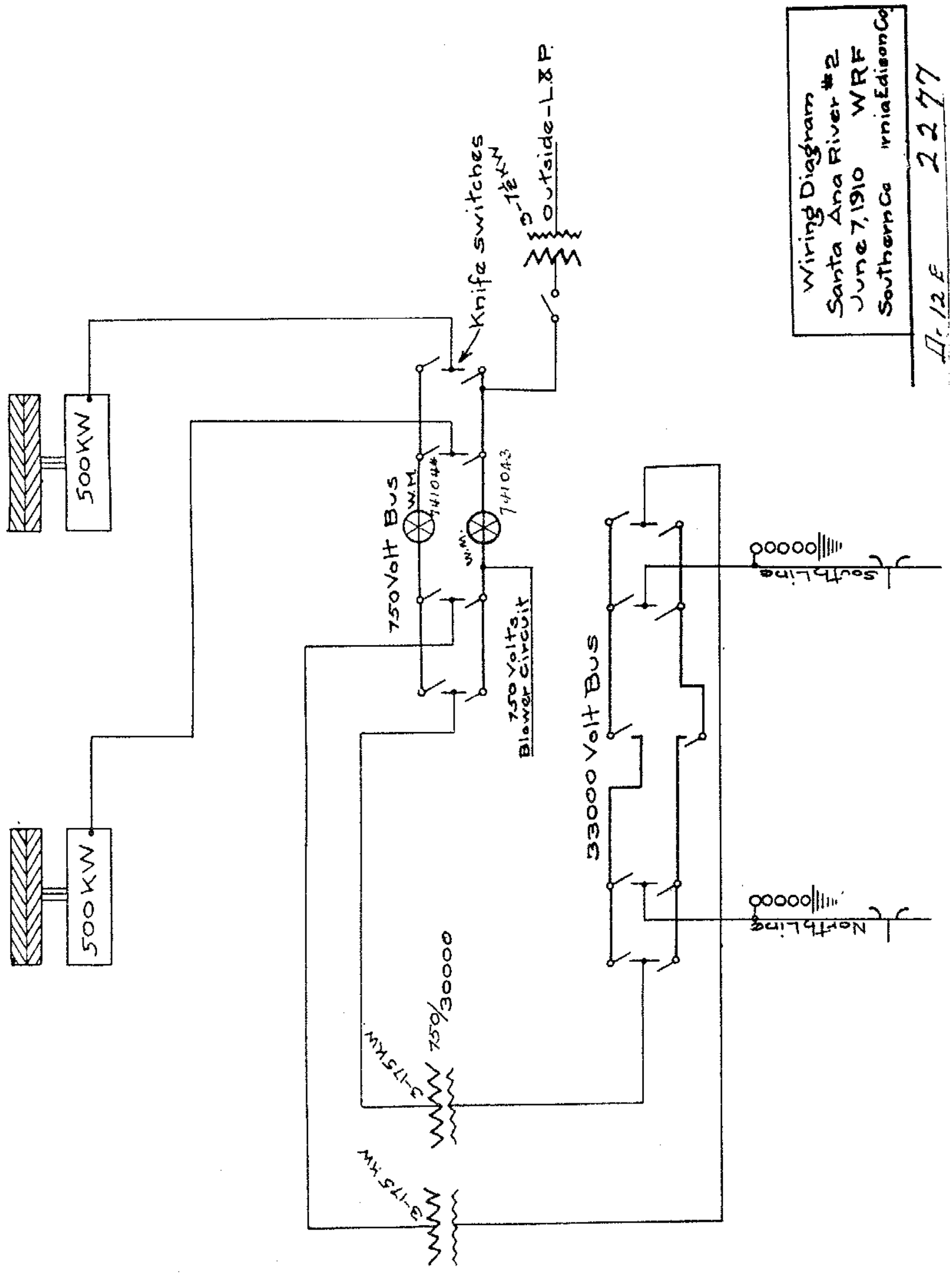
Originally, the two exciters that activated the electromagnets of the generators were water powered, located in the southwest corner of the powerhouse. The small water wheels that ran them were supplied with water from one of the "Y" branches by a small pipeline that ran under the powerhouse floor (Drawing 5393). The two exciters themselves were General Electric 17 kw, four pole, 40 horsepower, 125-volt continuous current (DC) generators, each driven by a small Doble wheel that was regulated by a Replogle governor (Fowler 1923:596). At present, only one of the exciters is in operation, and it is driven by a motor rather than the original water wheel (Secord 1985:7.11).

Transformers and Wiring

Originally, all six transformers at SAR 2 were installed inside the powerhouse itself, in the northwest corner. They were General Electric Type AB, Form B-1 transformers, air-cooled, that operated at 50 cycles and were rated at 175 kw. These transformers were arranged in two banks, and stepped up the generated current from 750 to 33,000 volts (SAR 2, 1909-1945; Fowler 1923:595-596).

Between the main room and the bay were the switchboards. The 750-volt board was on the ground floor; the 33,000-volt board, with its "open-cell switch compartments," was located above it. As Fowler reported, "there are single 750-volt and 33,000-volt busses, the latter being sectionized by air switches" (1923:596). In 1923, the circuit from each generator was brought to a triple-pole oil switch that connected the generator with the 750-volt bus. Similar switches connected each of the two transformer circuits to the 750-volt bus. A line, passing through an oil switch in the powerhouse, extended to the main transmission line between SAR 1 and Los Angeles. In 1923, this line was not equipped with lightning arresters (Fowler 1923:596), even though there was some sort of primitive grounding attached to the line as early as 1910 (Figure 25).

Figure 25. Wiring Diagram, SAR 2, 1910
(SAR 2 1909-1945)



7. SANTA ANA RIVER NO. 3

Santa Ana River No. 3 began operation a few months before SAR 2, in September 1904 (SAR 3, 1909-1945; Hinson 1956:36). SAR 3 is often called the Mentone plant because it was constructed by the Mentone Power Company, which had no connection with Edison Electric. The Mentone Power Company obtained the water rights for a powerhouse at the mouth of the canyon from C.A. Hooper and C. Weir sometime around 1900. In 1903, Mentone Power was bought by Pacific Power and Light Company, which was owned by Henry E. Huntington. At that time, Mentone Power was not absorbed into Pacific Power and Light, but rather became a wholly-owned subsidiary. It was under these circumstances that construction began on the "Mentone plant" conduit and powerhouse in June 1903 (Secord 1985:7.8,8.8-9; SAR 3, 1909-1945; Fowler 1923:596).

When the Mentone plant went on line in 1904, it had one 1500 kw, two-phase generator. The plant produced two-phase electricity because it used Westinghouse equipment. At that time, General Electric controlled the patents for most three-phase devices (Myers, personal communication 1992). From the very beginning, the two-phase power was modified to three-phase current in the powerhouse transformers (Fowler 1923:599). This power was then transmitted to the Stone Castle substation near Upland (Hinson 1956:36).

In 1910, Pacific Light and Power Company was reorganized to become the Pacific Light and Power Corporation. Seven years later, on 27 May 1917, Pacific Light and Power was bought by Edison Electric's successor, Southern California Edison. At that time, the name of the Mentone plant was formally changed to Santa Ana River Powerhouse No. 3 (Fowler 1923:596; Secord 1985:8.8-9). Aside from a brief article in *The Journal of Electricity, Power and Gas* (1907), and the engineering drawings and inventories that Edison acquired after 1917, the best information on the Mentone plant is preserved in Fowler's 1923 work on hydroelectric plants in California.

Intake and Conduit System

Due to the prior existence of the Santa Ana Canal, the development of the intake and conduit system for SAR 3 was much more complicated than was the case for either SAR 1 or 2. There were serious conflicts over water rights between the Mentone Power Company and Bear Valley Irrigation Company, which still had rights to the Santa Ana Canal at the turn of the century. According to a letter dated 10 February 1902, some Mentone Power employees actually worked to destroy the intake diversion dam of the old canal (Research Materials 1985: misc. letters).

Eventually, the matter was resolved so that both Mentone Power and Bear Valley Irrigation (and its successor, Bear Valley Mutual Water Company) could use the same intake. Originally, the headworks of SAR 3 used the upper portion of the old Santa Ana Canal, which diverted water in the immediate vicinity of SAR 2, at an elevation of about 2350 feet AMSL. According to Fowler, water diversion for the powerhouse had originally been managed by a small dam constructed of boulders and concrete that crossed the river channel diagonally "from the north to the south bank" (here Fowler probably means from the west to the east bank, since the river itself flows north-south in the vicinity of SAR 2).

On the "south" or east bank, the dam had two sets of sluice gates to remove sediments from the intake reservoir. Just below the intake, there was a "U"-shaped sandbox, which had a small timber inlet and outlet gate at the ends of the "U." It also had four sluicing gates in the loop of the "U." Through these gates, water-borne sand and other sediments could be flushed out of the system (Fowler 1923:596-597). From this description, it appears that some variation of the proposed intake for the Santa Ana Canal, only planned in 1895 at the time of William Hall's article, actually got constructed sometime between 1895 and 1904.

The erratic meanders of the Santa Ana River soon choked the "U"-shaped sandbox with so much debris that it was quickly abandoned. Thereafter, sand was removed from the SAR 3 conduit by two larger sandboxes just below Tunnel 1. When SAR 2 went on line, the tailrace of SAR 2 emptied into the SAR 3 conduit about 250 feet below the "U"-shaped sandbox, after which intake water from the river and the SAR 2 tailrace almost immediately entered Tunnel 1 (Fowler 1923:596-597).

The original diversion dam, sandbox, and canal above Tunnel 1, were all washed out by the flood of January 1916 (Fowler 1923:597). In the subsequent repairs, a temporary dam of rock and sand was created some 40 feet below the remains of the original dam. Water was then diverted into an earthen channel about 250 feet long. At the end of the channel, a low dam of cobblestones laid in mortar turned the water through a concrete gateway into a ditch about 175 feet long, 9 feet wide at the top, and 5.5 feet wide at the bottom, lined with cobblestones set in mortar. At the lower end of the ditch there was an emergency spillway on the downstream side of the ditch. There was also an inclined trash rack through which water ran into a wooden flume about 120 feet long that connected with Tunnel 1. A semi-circular steel flume, roofed with planking and protected by a 6-foot high masonry wall on the downstream side, brought the tailrace water from SAR 2 to the opening of Tunnel 1 (Fowler 1923:597).

To complicate matters further, there are two Tunnel 1's, parallel to each other and no more than about 30 feet apart. In Fowler's day (1923), Tunnel 1 would have been where it is today, the easternmost of the two. This tunnel, however, was not even finished when the Mentone plant went on line. Before the 1916 flood, Tunnel 1 would have been the same one used by the Santa Ana Canal, the westernmost of the two. After the 1916 flood destroyed the intake to the western tunnel, it was decided that the old Santa Ana Canal Tunnel 1 was too vulnerable to flood damage. The eastern tunnel, which had barely been started by Mentone Power during the early conflict over water rights, was then cleaned out and finished. The western tunnel, though currently abandoned, represents a fine example of the tunnel work of the old Santa Ana Canal (CA-130-R-2).

The rest of the conduit system largely coincided with the old Santa Ana Canal, although it is not known to just what degree the two systems overlapped. The tunnels almost surely were used as they were, with some completely lined with concrete, some partly lined, and others completely unlined (Drawing 541728). At least some original flumes had to be replaced, since flume failure was cited as one of the problems of the Santa Ana Canal. The original flumes for SAR 3 were probably redwood (Secord 1985:7.13).

According to the 1907 article, there were seven tunnels, with another one under construction to replace a flume. By the time of the 1909 inventory, the conduit system for the Mentone plant consisted of 4658 feet of tunnels, 901 feet of open canal, 615 feet of cement conduit, 7189 feet of wooden flumes, and 529 feet of wooden siphon (SAR 3, 1909-1945). These totals are contradicted by a 1915 inventory that was even more specific. Here, there were 5542.8 feet of tunnels, eight tunnels in all. These were listed as 5 feet 9 inches wide, and 7 feet high. The "open cement-lined ditch" was 1620 feet long, 5 feet 9 inches wide, and 4 feet deep. There was a 585-foot long covered cement flume, 5 feet 9 inches wide and 4 feet high. The wooden channels were "V"-shaped redwood flumes, 4290 feet in total length, 5 feet 6 inches wide and 4 feet deep. The wooden "stove-pipe" siphon, 52 inches in diameter, was listed as 551 feet long (SAR 3, 1909-1945). Unfortunately, not even the total lengths presented in the two inventories agree, so it is hard to say what changes, if any, were made to the conduit system in the early years of the twentieth century.

By the time of Fowler's inventory, the total length of the conduit is given as 2.7 miles. Counting Tunnel 1, there were eight tunnels. There was also a 551-foot inverted siphon over Warm Springs Canyon. Unfortunately, nothing specific is mentioned about the wooden flumes. The average grade of the conduit was listed as about 10 feet per mile, which is in line with the conduit system of SAR 1, but considerably steeper than the conduit system of SAR 2. The capacity of the conduit was an estimated 240 second-feet, of which only 80 second-feet were used by the SAR 3 powerhouse (Fowler 1923:598).

The water not used by the powerhouse was still subject to the water rights originally granted to the Bear Valley Irrigation Company, the original owners of the Santa Ana Canal. In 1910-1911, the Bear Valley Highline Canal was built or repaired on the bed of the old Santa Ana Canal. The Bear Valley Highline has since received the lion's share of the water brought to the forebay of SAR 3 (Fowler 1923:598; Hornbeck and Botts 1988:13, Figure 1). This was undoubtedly part of the compromise worked out between the water company and Mentone Power years before, and this agreement, or some modification of it, is still honored today.

Pressure Pipe

At the end of the conduit was a small forebay, 12 by 18 by 8 ft, constructed of reinforced concrete. The pressure pipe left the base of the forebay for the powerhouse (*Journal of Electricity, Power and Gas* 1907:2). The 1909 and 1915 inventories differ even to the length of the pressure pipe at SAR 3: 738 and 696 feet, respectively (SAR 3, 1909-1945). Fowler reported the length as 696 feet, from forebay to powerhouse. The 40-inch diameter pipe was lap riveted steel. It left the forebay and main canal at a point where the canal began to bend around the opening of the mouth of the canyon on its way toward Mill Creek. At this point, the pressure pipe left the small concrete box forebay located on the main canal. This pipe is only partly buried; the upper and lower portions are exposed. The static head of the pipe was noted to be 352 feet (Fowler 1923:598).

In addition to the pressure pipe, there was also an emergency spillway that went down the side of the canyon. This water would empty into a concrete ditch beside the powerhouse and enter the tailrace on the other side (Fowler 1923:598).

Physical Plant and Auxiliary Buildings

SAR 3 is the smallest of the three powerhouses in the Santa Ana River hydroelectric system, and has a number of distinctive architectural features that indicate it was not built by the same people responsible for SAR 1 and 2. The powerhouse building is about 40 x 30 feet, with the long axis oriented roughly north-south, perpendicular to the pressure pipe.

The earliest plans for the facility date to 1903 (CA-130-W-26). The transformers were to have been in the southeast corner of the building, adjacent to the switch gallery immediately to the north. A sliding door on the west wall was to be the main entrance. The building was also to have a 4-foot diameter galvanized iron ventilator set into the north wall (Drawing 52306).

The 1915 inventory mentioned that the powerhouse was a concrete construction, 31 x 41 feet in area, with an iron roof (SAR 3, 1909-1945). In 1923, after the powerhouse had passed to Edison, Fowler stated that it was a single monolithic concrete building (meaning that it had no internal steel supports), with outside measurements of 41 x 31 feet. It had a corrugated iron roof supported on a steel frame. In 1907, there was a "stationary 20-ton crane" on the side walls to install and adjust the machinery (*Journal of Electricity, Power and Gas* 1907:2). At present, a 5-ton capacity Shaw box crane extends along runners set into the east and west walls. The earliest plans of the 5-ton crane date to 1945 (Drawing 523856-2).

Between 1911 and circa 1923, there was a small lean-to located on the south side of the powerhouse for the transformers, which were moved outside in 1911. As had been planned, the main entrance to the powerhouse in 1923 was a sliding door in the front (west) wall, near the southwest corner. There was also a side door on the east end of the south wall, connecting the main building with the transformer area just outside (Fowler 1923:598). In the original plans and in the initial construction, there were double doors along the south wall at the east end; today, there is only a small single door in that location (CA-130-W-1).

A number of features made SAR 3 architecturally unique within the Santa Ana system. There was no monitor roof, as at SAR 1 and 2. Also, the gable section between the walls and roof was poured concrete, just like the walls. There was also more building detail, with capped buttresses at each corner, simple cast molding along both eaves at the north and south ends of the building, ceramic rain spouts, and rectangular steel frame casement windows (Secord 1985:7.8).

A number of auxiliary buildings surrounded the powerhouse. The 1909 inventory lists one two-story frame boardinghouse, 36 by 20 feet; three one-story frame cottages, each 36 x 26 feet; and one stable and one-story frame shed, 32 x 16 feet (SAR 3, 1909-1945; CA-130-55).

Water Wheel

The 1907 article mentioned that the SAR 3 water wheel was a "56-inch Stillwell-Bierce Smith Vaile 2750-horsepower water wheel" (*Journal of Electricity, Power and Gas* 1907:2). Just two years later, the 1909 inventory described the SAR 3 water wheel as a double Doble wheel, 2635 horsepower, with a Type B Lombard governor. The wheel was direct connected to the generator, which formed the only generating unit in the powerhouse. SAR 3 never had more than one water wheel/generator combination (SAR 3, 1909-1945; Drawing 52880).

Other sources mention that this double Doble impulse wheel had two runners, which meant that it was really two wheels in one, with a water jet for each runner. Both runners, however, had a single housing (Fryer 1980:28; CA-130-W-23). Each wheel had 16 buckets, making a wheel diameter of 54 inches (Secord 1985:7.11; Fowler 1923:599).

To power this double wheel, the pressure pipe entered the powerhouse above the floor line (another unique feature within the Santa Ana system) and through a large gate valve. The pipe then branched into two stationary nozzles. In 1923, each nozzle had a needle that was still operated by a Lombard governor, Type B. The two rotors of the double wheel were mounted on the same shaft and were held in position by a three-bearing support. The whole wheel with the two rotors was covered by a single hood. The rated capacity of the two rotors was 2600 horsepower (Fowler 1923:599).

This double Doble water wheel remained in service for more than two decades after the Edison acquisition. It was finally replaced by an altogether different type of wheel in the 1940s, and it is this later wheel that is found today at SAR 3. This change and others that occurred to the system will be discussed in the sections devoted to powerhouse alterations, most of which occurred in the 1920s and the years that followed.

Generators and Exciters

The generating unit of SAR 3 occupied a central position within the powerhouse. The water wheel was located toward the center of the room, with the generator located to its north. The exciters and governors were all near the generating unit, leaving the southwest part of the room for the switchboard and wiring.

The original generator at SAR 3 was a 1500 kw revolving field Westinghouse machine that operated at 50 cycles, 300 rpm, and generated 2200 volts. Unlike every other generator in the canyon, this machine produced two-phase electrical current (*Journal of Electricity, Power and Gas* 1907:2; SAR 3, 1909-45; Fowler 1923:599).

The original exciter was a 22.5 kw multipolar 125-volt Westinghouse DC generator, as inferred from the 1907 article and 1909 inventory. By the time of the 1915 inventory, there was a spare exciter, rated at 65 kw and made by General Electric (SAR 3, 1909-1945). By 1923, there were two sets of exciters. One set, attached to a small Doble water wheel, consisted of the Westinghouse 22.5 kw DC generator and its back-up source of power, a Westinghouse CCL 40 horsepower, 2200-volt, 78 ampere, two-phase, 50 cycle induction motor. The second set was a small DC generator belted directly to the main generator shaft rather than powered by an independent motor or impulse wheel. This was a 4-pole General

Electric, Type MP continuous current (DC) generator, rated at 65 kw, 125 volts, and 520 amperes (Fowler 1923:599).

Wiring, Switchboard, and Transformers

According to a 1909 diagram, most of the original wiring and associated equipment was made by Westinghouse (Drawing 52880). The switchboard itself was located against the south wall; the switches were in the gallery above the switchboard (Fowler 1923:598-599).

The transformation from two-phase to three-phase alternating current was achieved by the so-called Scott system of wiring located within the transformers themselves. The original transformers were two Stanley water-cooled and oil-insulated SKC machines, 3000 shell type, each rated at 750 kw, 50 cycles, and capable of transforming 2000 volts, two-phase current, to 17,500 volts, three-phase. These transformers were protected by three 30,000-volt Westinghouse lightning arresters situated on a concrete footing outside the powerhouse, immediately behind the switchboard. According to Fowler, these Stanley transformers were installed when the plant first went on line and were still in use in 1923 (*Journal of Electricity, Power and Gas* 1907:2; SAR 3, 1909-1945; Fowler 1923:598-599).

According to plans and early photographs, the transformers were located in the 8 by 14 foot compartment set aside for them in the southeast corner of the building (CA-130-W-24). According to Fowler, they were moved outside in 1911. By the time Fowler saw them in 1923, they were protected by the lean-to against the south wall (Fowler 1923:598). Apparently there is some contradiction as to when the transformers were placed outside. Either Fowler was incorrect, or the date ascribed to CA-130-W-24 is wrong. The latter would appear to be more likely. To complicate matters further, the 1907 article stated that the transformer room was built "just off the main building." From a very poor quality photograph that accompanied the article, there is a room off the west wall of the powerhouse that may have been the one referenced. This room was almost surely gone by Fowler's time, since it was not mentioned.

On the 15,000-volt side, the transformers were connected to either the north or south line busses through single-phase oil switches (Fowler 1923:599). Originally, there were two 3-pole Kelman oil switches capable of dealing with the 15,000-volt current created by the transformers. These switches were hand-controlled (SAR 3, 1909-1945). By the time power left the building, there were two 15,000-volt circuits that exited through six tile pipe outlets adjacent to the switch gallery (Fowler 1923:598-599).

Plans for Other Powerhouses in the Canyon

Years before Edison's acquisition of the Mentone plant, at least two sets of plans were drawn up for two additional powerhouses in the Santa Ana River canyon. Both were upstream from SAR 1, since the areas downstream had already been developed. One set dates to 1903 (Pearson 1903); the other dates to around 1910. It would appear that nothing came of the earlier plans, but the plans dating from around 1910 were to have been built by Union Power Company, a subsidiary jointly owned by both Edison Electric and Pacific Light and Power, which then still possessed the Mentone plant (Secord 1985:8.8; Myers, personal communication 1988).

The Union Power plants were proposed as early as 1909, and construction was listed as "in progress" the following year (Finkle 1910:1). The plants, however, were never completed, and it does not appear that work ever progressed beyond some preliminary conduit survey and limited tunnel excavation. The difficulty of accessing this area probably played a role in the abandonment of the work, but it seems more likely that by the 1910s, Edison's large projects in the Sierra Nevada, and the new steam plant at Long Beach, made further development of the Santa Ana River seem less urgent.

8. THE SANTA ANA RIVER HYDROELECTRIC COMMUNITY, 1905-1921

Historical and archaeological information about the work camps of those engaged in powerhouse construction has been presented in a focused study (Foster, Greenwood, and Duffield 1988). The workers were housed in tents in areas of concentrated activity in the upper canyon and later, at Warm Springs. The earlier clusters were loosely and randomly arranged. Wage rates in 1898 ranged from $3.50 day for the head foreman, to $ 1.75 for laborers. The teamster earned $ 4.00, but was expected to provide his own team. Other positions on the payroll included blacksmith, carpenter, miner, hoist labor, stone mason, plumber, plasterer, roadman, and waterboy. A fixed amount, $ 19.90 per month, was deducted for housing, in addition to any purchases at the company store. Peak employment during the construction of SAR 1 was 691 in 1898 (Ibid. 139). The later encampments were formally organized in a structured configuration. A 1926 photograph of the Warm Springs camp (SCE Collection, Photo. No. 11761) illustrates 26 tent-cabins spaced equidistant in two parallel rows with well defined equipment, storage, and activity areas. The historic road which served the canyon has been described in Hatheway 1987.

The more permanent housing provided for those who operated the completed powerhouses was the subject of Foster, Swanson, and Hampson 1989. Most of the research concentrated specifically on the operator housing immediately adjacent to SAR 2, which was the subject of an archaeological assessment. One section of the 1989 report, however, concerned the hydroelectric community within the canyon as a whole, and offers a glimpse of life in the hydroelectric community in the years before semi-automation at the powerhouses began to reduce the Edison staff in 1921.

The first Edison communities in the Santa Ana River canyon were the work camps established for the construction of SAR 1. Work on the tunnels began in the summer of 1897; work on the powerhouse itself began in the fall of that year. As many as 450 crewmen were situated in the canyon during this period of construction. Most of the SAR 1 construction work was completed by December of 1898, and the number of Edison employees decreased to around 40. By 1900, the maintenance staff had decreased to 12 (Foster et al. 1988:15-17). Thereafter, the regular operators of the powerhouse would form the bulk of the Edison community in the canyon. Only when SAR 2 was built, and later, in the aftermath of floods, would the community be swelled by construction crews.

By all accounts, the dwellings and other structures adjacent to SAR 1 and (after 1917) SAR 3 were the nerve centers for the hydroelectric community within the canyon. The structures behind SAR 2 were more crude than similar quarters at either of the other two powerhouses (Don Anderson, Horace Hinckley, Willis Cadwallader, personal communications 1988). The best houses in the canyon were located at SAR 1, Warm Springs, or adjacent to SAR 3. Most of the workers who maintained the system lived at either SAR 1 or 3, presumably in houses less pretentious than the operators' quarters. At SAR 2, there was a chief engineer, the powerhouse operators, and perhaps some flume cleaners, comprising a total population of between 10 and 15 people, including families (Don Anderson, personal communication 1988).

The people who tended SAR 2 were part of a larger community of employees who watched over the entire hydroelectric system in the canyon. With the exception of SAR 3 until 1917, they were all Edison employees, and further united by their isolation from the established communities in the San Bernardino Valley. Whether they worked for Edison or Mentone Power, or lived independently at Warm Springs, the local inhabitants all knew each other. In the 1900s and 1910s, before radio and television, they socialized frequently.

In 1905, the entire canyon was surveyed by Isaac Ford, who prepared a map showing the permanent structures between the powerhouses. The four houses on the terrace behind SAR 2 are shown, as is the powerhouse itself. There may be other constructions on the floor of the canyon, but the condition of the map does not allow definite identification. There appear to be three houses at the mouth of Warm Springs Canyon, 0.75 mile south of SAR 2, and a single structure about 0.25 mile north of the powerhouse. Four or five structures are shown at SAR 1, and it is difficult to determine the number of structures at SAR 3.

The housing for those who operated the facilities was of a more permanent nature than the temporary tent clusters. In both siting on the slopes behind the powerhouses and architecture, they reflected the hierarchy from foreman to those who lived in bunkhouses. The foreman lived closest to SAR 2, in the largest house. It was plumbed and wired, with a cement slab, shingle roof, plaster on the interior walls, mortared stone retaining walls, and formal paths and planting beds. Archaeological evidence suggested red paint. The six rooms included living and dining rooms, two bedrooms, an office, pantry, screened and open porches. It was clad in horizontal rustic siding, with board and batten aprons to cover the gap resulting from establishing a level pad on the slope. Those of lower rank had four-room board and batten cottages with two bedrooms, dining room, and kitchen, while the bunkhouse was a single chamber to accommodate up to eight cots, with an attached open wash room (Foster, Swanson, and Hampson 1989:43-61).

Much information about early social life in the canyon has been provided by Willis Cadwallader, who lived in the Warm Springs area until he was seven years of age, when his family moved into the valley below so that he could go to school. Cadwallader lived in the area between 1909 and 1916. His sister, Ella Cadwallader, was stillborn in 1913 and was buried in the canyon between Warm

Springs and SAR 3, along with "Baby Richardson" (personal communication 1988). The remains of the infants were disinterred and reburied in 1990 to make way for the dam reservoir. The original grave sites, however, are still commemorated (Taylor, personal communication 1992).

According to Cadwallader, about three employees and their families lived at SAR 2, which was the closest powerhouse to Warm Springs. In those days, all of the employees and their families were "white." He recalled that there were children present because on occasion he played with them. Cadwallader remembered only a few of the family names: Webster, Snider, Butterfield, and Patterson. SAR 2 required at least three operators because the powerhouse had to be monitored constantly, and each employee had a shift of either 8 or 12 hours (personal communication 1988).

By 1913, the canyon was connected to a system of wireless communication with the radio stations Edison established at Lytle Creek and Mill Creek 3 (Witte 1913:13). In April of that year, Chief Butterfield told the Edison publication in Los Angeles that the refurbishings and improvements then being made to SAR 1 would turn the powerhouse into a "first class summer resort." Much of the present physical appearance of the SAR 1 complex dates to this period. Butterfield was proud of the new barn just completed, and the corral that was still under construction. The chief engineer also commented on the new lawn added around the SAR 1 powerhouse, the repainting of the buildings, and the coat of "Edison red" that had been given to the generators (*Edison Current Topics* 1913).

At the very least, the new lawn was ruined by the 1916 flood, which was universally acknowledged to have been the worst disaster to the Santa Ana system since its inception. All three powerhouses in the Santa Ana canyon were temporarily knocked out by the flood. Seven people lost their lives in the canyon as a result of the flooding, although none of them was an Edison employee. In the aftermath, it was noted that "Butterfield and the boys" saved the powerhouses through their timely intervention (Pearson 1916:26).

Unpublished Edison records, presently archived by William Myers, provided more detail on the work schedule and responsibilities of the employees at SAR 2. Although no early payroll or correspondence records for Powerhouse 2 have been found (Myers, personal communication 1988), there are some existing records in the form of powerhouse log books, a horse-team record book, and a supply log, dated 1914-1917. The documents reflect life at Powerhouse 2, especially between 1906 and 1916, the period of most of the existing data. This coincides well with the heyday of the Santa Ana hydroelectric community, which spanned the years between 1905, the inception of SAR 2, and 1921, when the powerhouses went to semi-automatic control and began to operate with a reduced staff.

The log books were daily records of power production. One operator signed in at midnight for the A.M. shift, kept records of power production during his watch, and signed out at noon, to be relieved by the other operator for the P.M. shift. During the entire period in question, operators worked 12-hour shifts. The earliest log book, for 1906-1907, gives the last names of the Powerhouse 2 operators: Slamal and Varney (*Santa Ana 2 Log Book* 1906-1907). By the end of the log, Varney had been replaced by Stooksberry. Occasionally the name Coultrap shows up for a shift.

Apparently Coultrap was the chief engineer for SAR 2. On January 4, 1907, he entered a warning to the operators in the log book that, "no one is allowed to adjust any meters or make any changes until [obtaining] consent from foreman who has to get consent from [the] office" (*Santa Ana 2 Log Book* 1906-1907).

In 1908, Coultrap was still the chief engineer and Slamal was still an operator. The other operator was a man by the name of Blackman (*Santa Ana 2 Log Book* 1908). By 1911, the operators were T. Milton Rice and Walter Adams. Snider appears in the log book for the first time when he took a shift on February 14. In that year, Snider did not work many shifts, but it does not appear that he was the chief engineer. He may have been a new employee, or he might have been based at SAR 1 and only "on loan" to Powerhouse 2, as occasionally happened (*Santa Ana 2 Log Book* 1911).

By 1913, there appeared to be three operators at SAR 2: Hughes, Webster, and Snider. They worked in shifts that were somewhat irregular, but the rotation appeared to have changed from the earlier days. Whereas it used to be 1,2,1,2,1,2, relieved occasionally by the chief engineer, the new pattern appeared to be 1,2,1,2,1,2, then 1,3,1,3,1,3, then 2,3,2,3,2,3 (*Santa Ana 2 Log Book* 1913).

By this time, there is overlap with other record books that flesh out the daily schedule at the powerhouses. The Santa Ana 2 Team Record, dated 1911-1916, was a daily log kept by the teamster, who had to record the destination and purpose of each trip. On about half the days of any given month, the horse team never left the barn. On other days, the teamster was sent to Crafton or East Highlands for food, hay, or mail runs; to the Mentone Powerhouse at the mouth of the canyon; to Redlands for food, hardware, or a doctor. In addition, the teamster had to haul oil and wood to the operators' houses, and transport employees.

It should be noted that a medical doctor, Dr. Hill, was then living in the canyon, at Warm Springs, on a piece of land commonly referred to as the "Old Hill Ranch." One of the surviving workers at SAR 2, Ken Coble, recalled that Dr. Hill delivered his daughter at one of the SAR 2 houses in 1927 (personal communication 1992).

Compared to all of the excursions between SAR 2 and the valley below, the teamster based at SAR 2 did not make as many trips to SAR 1 might be expected. Part of the reason may have been the difficulty of the journey. On April 18, 1911, the teamster noted that he had to take an employee from East Highlands to the headworks camp of Powerhouse 1, and that his was the first team to get through that season.

One function of the teamster was to carry employees and their families in and out of the canyon on their days off. In 1913, Webster and his wife, and Snider and his wife were frequent users of this service. The teamster also had to move employees who were transferred from one powerhouse to another. Occasionally, though, the teamster used the rig for his own purposes. In one entry he stated that he was going to Redlands, "to spend his money" (*Santa Ana 2 Team Record*, 1911-1916).

Perhaps the most remarkable record of life at Powerhouse 2 is preserved in the eclectic *Santa Ana 2 Supply Log* for 1914-1917. It contains a bit of everything and must have been a catch-all notebook used for compiling wages at the powerhouse, recording the number of meals served, and who ordered what at the commissary. There is a tally of bills owed to various business establishments in the valley, and even an "Inventory of Cooking Utensils, Dishes, and groceries at SAR 1, Taken February 16, 1916" and an "Inventory of Supplies at Camp, Mouth of the Canyon, February 24, 1916."

The *Supply Log* contains a summary of employee activities at Powerhouse 2 for the months of October, November, and December, 1914. During this period, J.J. Bryan, E.K. Curry, and G.O. Hughes shared the powerhouse shifts; Hughes and Curry apparently bore the brunt of this burden. These operators apparently worked a shift for five to seven days in a row, then spent an equal number of days assigned to other tasks such as repairing the forebay shaft, working on the phone lines, or general cleaning. The teamster during this period was George Siler, for it was noted that he hauled oil, hay, lumber, freight, and other supplies. George Turley and J.W. Styer spent most of their time working on the "WC," which presumably was the water canal feeding into the powerhouse; they also worked on the flume (*Santa Ana 2 Supply Log* 1914-1917).

A number of other people are named on these same pages, although their tasks are not always specified. They were definitely Edison employees because their monthly pay rates were recorded together with those of the people mentioned above. It is not certain, however, that all worked at Powerhouse 2, since much information in this log pertains to Powerhouse 1. Because most of the notes in this log were rough, apparently meant to be transferred to a more official document, it is often not specified which employees worked at which powerplant. However, it appears that A.W. Butterfield, superintendent, spent a good part of his time at Powerhouse 2, in addition to his duties at Powerhouse 1.

His monthly salary was 115 dollars. The operators' salaries were the next highest on the scale: J.J. Bryan received 80 dollars; Hughes, 75 dollars; and Curry, 70. Siler, the teamster, received 70 dollars, while Turley and Styer, the water canal and flume tenders, received 50 and 70 dollars, respectively. "Mrs. S." received a monthly salary of 10 dollars, by far the lowest on the scale. She was the cook at Powerhouse 2, and might have been married to either Siler or Styer. Four other names were listed, but it is not certain what they did or where they worked (*Santa Ana 2 Supply Log* 1914-1917).

One of the most intriguing entries in the *Supply Log* was a tally of meals served at "SAR 1 and Head Works" for the early months of 1916. Despite the heading, it appears that all Edison employees in the canyon were entered into the record, including those at Powerhouse 2. The very first meal log, which is the only one untitled and undated, but probably January 1916, apparently lists all employees in the canyon; people who definitely worked at SAR 2 are included. There were 12 salaried employees, including three cooks, and 23 daily wage earners. It seems likely that the meals were served in three different locations: SAR 1, the SAR 1 Head Works, and SAR 2. Certainly the three cooks were in these locations. John Brooks received 50 dollars, presumably at Powerhouse 1, which had the largest camp; the Head Works cook, McGovern, received 35 dollars; while Mrs. Patterson, wife of the teamster located at SAR 2 (*Santa Ana 2 Team Record* 1911-1916), received 10 dollars. Most of the meal entries ceased abruptly on the 16th, the first day of the January 1916 flood (*Santa Ana 2 Supply Log* 1914-1917).

Perhaps because of the flood, inventories were taken in February of the kitchen and food supplies at SAR 1 and a storehouse "at the mouth of the canyon." These inventories suggest that the vast majority of the food provided by the company was either dried or canned. The storehouse contained items in bulk, such as canned goods, dried beans, coffee, baking powder, dried apples, sugar, flour, and eggs. The food recorded at SAR 1 was much more varied, but was essentially preserved the same way - dried or canned: canned vegetables, canned milk, corn meal, rice, and varieties of beans.

Edison charged employees 25 cents for each meal, and offered three meals a day (*Santa Ana 2 Supply Log* 1914-1917). No charge was noted for operator housing, and it does not appear to have been deducted out of the salaries. Apparently Edison provided free living quarters; this agrees with what Don Anderson remembered about the housing arrangements in the canyon (personal communication 1988). It seems likely that the bunkhouses were reserved for the daily wage-earners; again, there is no indication that they paid for housing.

Some of the last entries in the *Supply Log* are commissary records. With the influx of workers into the canyon in the spring of 1916 to repair flood damage (84 people were fed in March), the commissary must have done a brisk business. The most common items signed for were work clothes, soap, tobacco and rolling papers, pipes, matches, towels, small food items, and even mosquito nets. Customers were expected to settle their accounts at the end of each month (*Santa Ana 2 Supply Log* 1914-1917).

A record was even preserved of the companies with which Edison regularly did business in early 1916. Almost everything employees ate, needed, or worked with, had to be bought on the open market, and Edison had accounts with a wide range of firms in the valley. A partial but representative listing of these vendors is provided below, together with what was normally purchased:

F.C. Creamery - dairy products
D.H. Richardson - food, general produce
J.J. Suess - food
Cudahy Packing Co. - meat
Wilson & Barron - meat
E.M. Cope Commercial Co. - hardware, tubs, pitchers
L. Sherrard Blacksmith - smithing
Harvey's Blacksmith - smithing
Home Oil Co. - oil
Redlands Hardware & Stove Co. - hardware
Thomas Carroll - tobacco
Reid & Findley - clothes
Redlands Shoe Parlor - shoes
Russ Lumber Co. - lumber
Ponny Livery & Transfer Co. - horse feed
Osborn Iron Works - hardware (*Santa Ana 2 Supply Log* 1914-1917).

Living at such a distance from established communities was particularly tough on families. Children at Warm Springs and at the powerhouses were transported to Mentone to attend school, probably by special teamster. Arrangements were made in town for the children to stay for days on end in case of winter storms when the roads were washed out (Don Anderson, personal communication 1988). Going to school was apparently a hardship, both for children and parents. The Cadwalladers moved out of the canyon in 1916 so that Willis could go to school regularly; his parents kept him back a year, not even enrolling him until they could make the move (Willis Cadwallader, personal communication 1988).

Aside from the station log books, which recorded shift changes and power output, there is little written information on the powerhouse community in the 1920s. After the switch-over to semi-automatic operation in 1921 (Southern California Edison Co. 1947), there was a considerable reduction in staff. Only two operators and their families stayed at SAR 2, and the local alarm system allowed the operators greater freedom during their shifts (Coble, personal communication 1988). There were still two shifts per day, changing at 8 A.M. and 8 P.M. The main shift, however, coincided with the daylight hours, when most of the daily information was recorded (*Santa Ana 2 Log Book* 1923-1924, 1926-1927).

By the 1920s, company meals were no longer served at Powerhouse 2. They were offered only at SAR 1, the SAR 1 Head Works, and at Powerhouse 3 (formerly the Mentone Power Plant). The charge was now 50 cents for each meal (Coble, personal communication 1988).

By the 1920s, the peak of the powerhouse communities had already passed. This coincided with a relative decline in the importance of Edison's hydro system in the Santa Ana River canyon, which had already been outdistanced by other hydroelectric systems. In the early 1900s, Edison inaugurated the Kern River project. Soon it rivaled and then surpassed the Santa Ana System, even with the inclusion of the Mentone Power Plant as SAR 3 in 1917 (Research Materials 1985; Myers, personal communication 1988). By the 1920s, it was clear that the system would not expand any further, and had entered a period of retrenchment. Union Power finally abandoned plans for two additional power plants above SAR 1. SAR 2 was in fact one of the last small-stream power plants built by Edison (William Myers, personal communication 1988). Henceforth the company would concentrate on the potential for large-scale hydroelectric power in the Sierra.

9. DEVELOPMENT OF THE EDISON DISTRIBUTION SYSTEM

Hydroelectric Developments in the Sierra Nevada

The hydroelectric potential in the Sierra Nevada was first tapped around the turn of the century, with development accelerating throughout the early decades of the twentieth century. This growth was prompted by the demands of the growing communities of southern California. It was only at this time that commercial production of electricity was taken beyond the plateau achieved by the first Santa Ana River plant. Although details of this development are beyond the scope of the current study, some discussion of the hydroelectric development of the lower Sierra Nevada is essential in order to place the Santa Ana River system in its modern context.

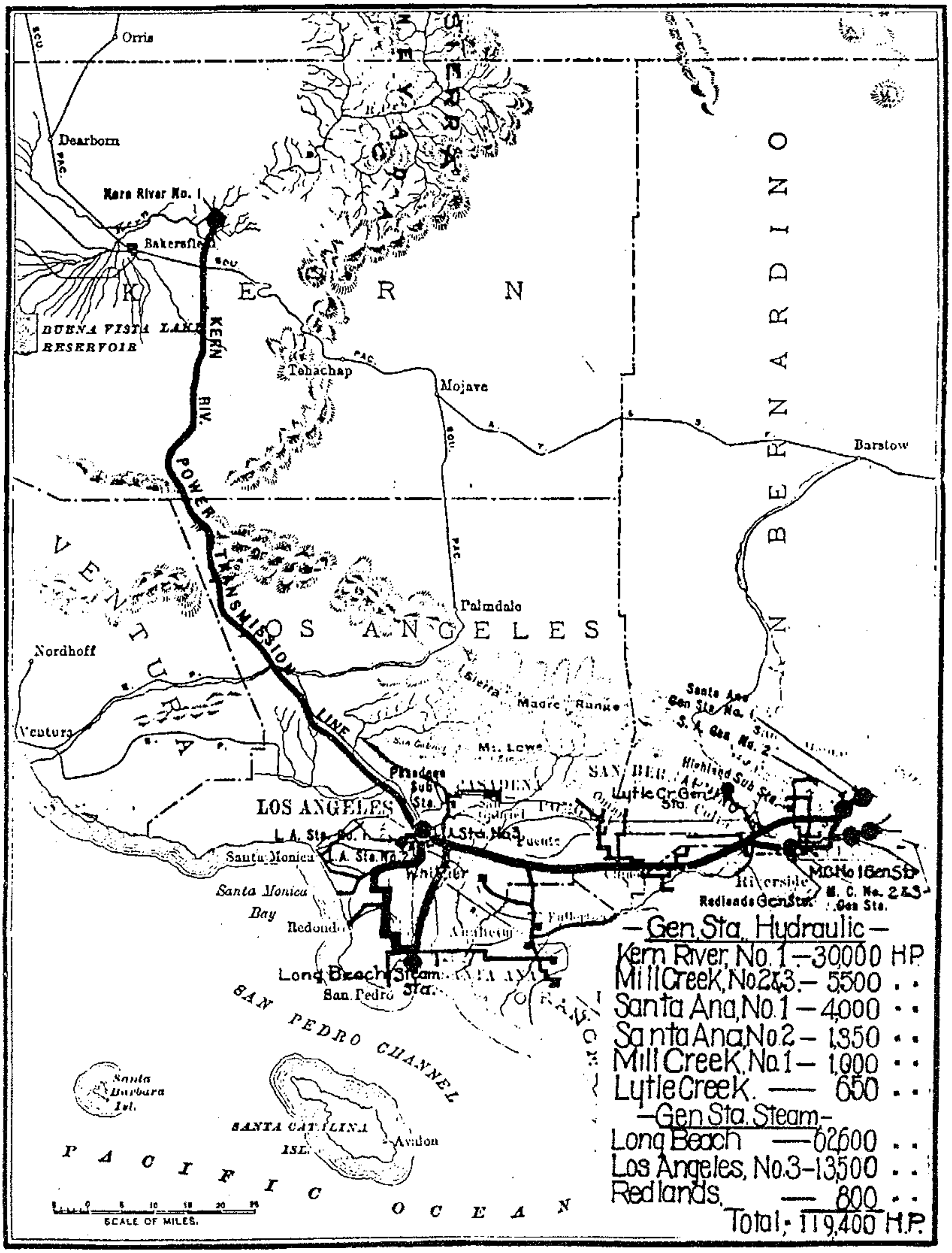
Possibly the first hydroelectric facility in the lower Sierra Nevada was the first Kaweah plant, which began operation in June 1899 with three 450 kw generators producing 17,000 volts for Visalia and Porterville; later, the current was raised to 33,000 volts. This powerhouse was considered to be the beginning of the Mt. Whitney Power Company system. Kaweah No. 2 followed in 1905 (Hinson 1956:23, 38).

Los Angeles utilities were involved with the construction of the Borel plant on the Kern River. Built by the Kern River Company, Borel went on line in December 1904 with five 2000 kw generators. Voltage was stepped up from 2200 to 57,000 volts and then transmitted 127 miles to Los Angeles, where it was received at the Kern substation on Mission Road just east of Lincoln Park with a current of 55,000 volts (Hinson 1956:36-37). With Borel, the first Santa Ana River powerhouse was finally surpassed in almost every technological field.

The Santa Ana River system was clearly overshadowed by further developments along the Kern River. The Kern River No. 1 plant was actually built by the Edison Electric Company, which began construction in January 1902. The plant was put on line in May 1907, and by July had four 5000 kw generators in operation. This station had a transmission line almost as long as Borel: 118 miles (Figure 26). The voltage transmitted along the line, however, was considerably higher. According to one source, the current was stepped up to 70,000 volts so as to provide 60,000 volts when it reached Los Angeles (Pearson 1912d:17). Other sources maintain that the initial current was 75,000 volts (Hinson 1956:39; Myers 1986:47).

The transmission line for the Kern River plant was designed by the same man responsible for the historic Santa Ana River No. 1 transmission line, James A. Lighthipe (Myers 1986:47). Lighthipe

Figure 26. Southern California Edison Company
Transmission Lines, 1913
(Fryer 1980:56a)



again made engineering history with a new transmission line. Steel towers were used along the entire route, with spans as great as 700 feet (Pearson 1912d:17; Myers 1986:47). Originally, this line was equipped with the old pin type of porcelain insulator, simply a larger version of the model used at Borel. These were bolted onto the top of the steel arms. This pin type of insulator was replaced by suspension insulators in 1915 (Hinson 1956:39; Myers 1986:49). After this, suspension insulators, which hung down from the tower arms, became the standard for high voltage transmission lines (Rustebakke 1983:124).

Other developments would later take place on the Kern River, but even these were quickly overshadowed by the much larger developments on Big Creek, about 140 miles farther to the north. The hydroelectric plants on Big Creek, begun in the 1910s, had become the overwhelming concern of Edison's Hydro Department by the 1920s (Operating Department 1929). It is fair to say that Big Creek became as important to Los Angeles for electricity as the Owens Valley was for water (Myers 1991b:236-247).

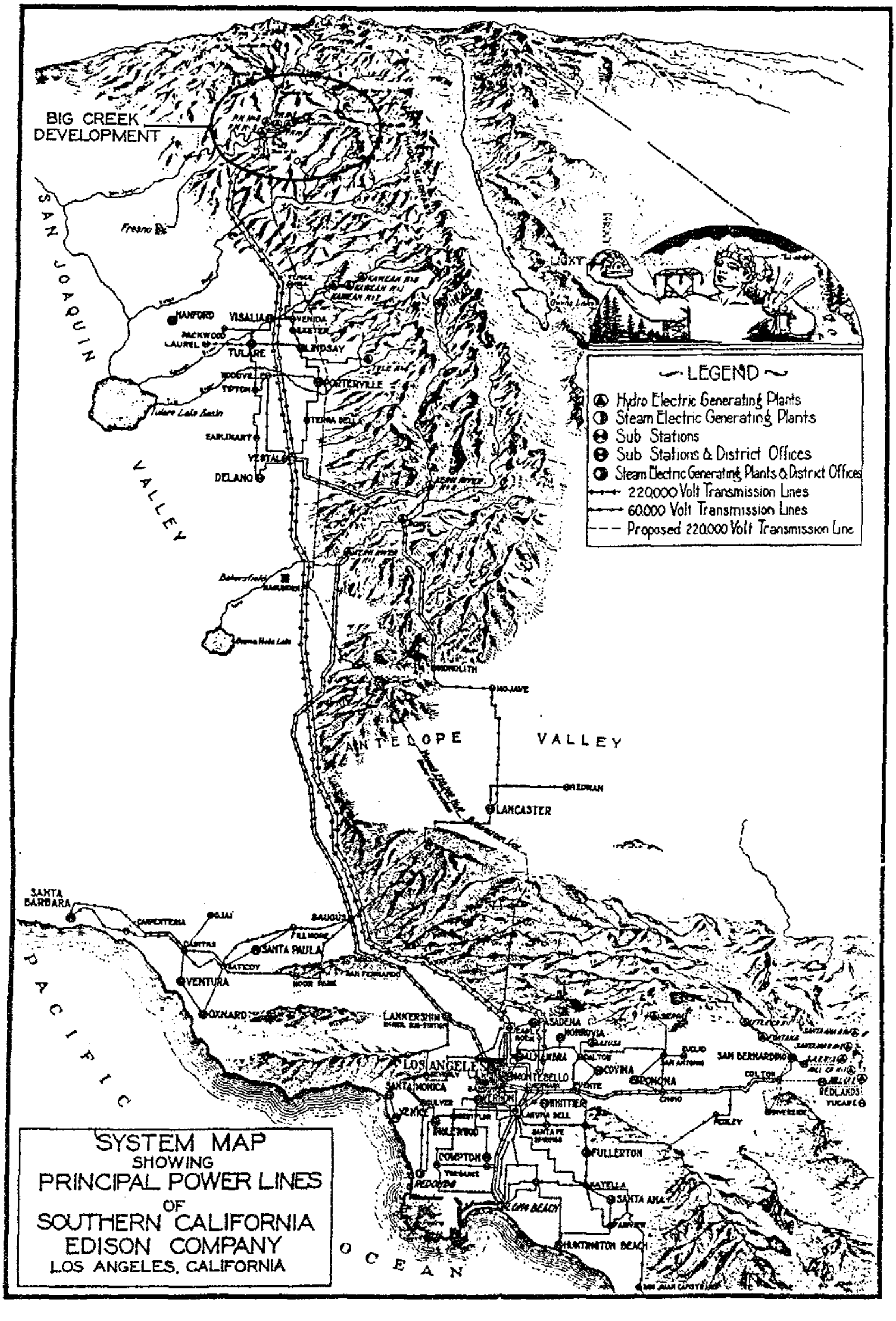
The first Big Creek project was begun by Pacific Light and Power in 1910 and took three years to complete. Big Creek No. 1 came on line in November 1913, with two 17,500 kw generators. By December, Big Creek No. 2 had one 17,500 kw generator in operation, followed by another in January 1914. Power was transmitted to Los Angeles with current stepped up to 150,000 volts (Hinson 1956:44).

Edison acquired the Big Creek operation directly after its consolidation with Pacific Light and Power in May 1917 (Myers 1991b:236-247). Thereafter, the Big Creek hydro plants began to provide power to agricultural operations in portions of the San Joaquin Valley, in addition to Los Angeles (Figure 27). When Big Creek No. 3 went into operation in September 1923, it was the biggest Edison plant that had ever been built, with three 28,000 kw vertical generators, and current stepped up to 220,000 volts -- another first in commercial electrical transmission. The transformers, switches, and busses for this new 220,000-volt line were so powerful that this whole part of the operation was set up outdoors, just outside the powerhouse (Hinson 1956:49-53), thus solidifying another trend in electrical energy generation.

Evolution of the Edison System, ca. 1910-1940s

The inexorable force behind the more powerful plants and longer transmission lines was the population growth of southern California and the increasing demands this population made on electrical power. The counties that comprise the Los Angeles Basin saw a phenomenal growth in the early decades of the twentieth century. Los Angeles County experienced the lion's share of this growth, jumping from 170,298 people in 1900, to 504,131 in 1910, and reaching 936,455 by 1920. The populations of Orange, San

Figure 27. Southern California Edison Company
Transmission Lines, 1925
(Fryer 1980:56d)



Bernardino, and Riverside counties, although much smaller, at least doubled every decade during this period, most notably between 1900 and 1910 (Fowler 1923:449).

To keep up with increasing demand, power generation had to make similar leaps. In 1908, Edison's hydroelectric powerhouses produced 29,000 kilowatts, with steam plants providing another 16,595 kilowatts. By 1918, with the first Big Creek hydro plant in Edison's possession, hydroelectric production jumped to around 109,000 kilowatts, with steam trailing at 75,595 (Myers 1991b:84). These figures jumped again as other Big Creek projects went on line. By 1928, hydroelectric power accounted for 440,000 kilowatts, with steam providing 353,000 kilowatts (Hinson 1956:42,48,57).

The decade after 1929 coincided with the Great Depression of the 1930s, and the Edison system grew only modestly during this period. In 1938, power levels were only little more than they were in 1929: hydro power, 490,000 kilowatts; steam power, 380,000 kilowatts (Hinson 1956:59).

Edison's distribution network also had to keep pace between the 1900s and 1920s. The first real transmission network began with the advent of Santa Ana River No. 1 and its 33,000-volt current. Before this, output varied greatly from powerhouse to powerhouse, with distribution tied to the closest generating plant. Work on the Kern River resulted in a 66,000 volt network by 1914, and by the 1920s, Big Creek led to a 220,000 volt transmission network that remained state of the art until at least the 1950s (Hinson 1956:61).

The 1900s and 1910s were recognized even then as the beginning of a new era in local electrical generation. Leading the way was the demand for power, which had already replaced lighting as the major use of electricity. By 1912, the ratio of power to lighting was already 5 to 1 (Kennedy 1912:5), and this occurred despite the fact that plugs for household electrical appliances still had to be screwed into a socket like a light bulb (*Edison Current Topics* 1913).

The need for electricity, for uses beyond lighting, was clearly expanding and in southern California, much of that future was made possible by hydro power and the success of long transmission lines (Pearson 1912:3). This era was inaugurated by the success of the Santa Ana River hydroelectric system, and reflected in the personnel advanced within the Edison company. By 1912, Benjamin Pearson, former SAR 1 worker and supervisor, was general superintendent of the Edison Electric Company. During this period John Miller was president of the company, and it was his dream to extend the Edison network to the Sierra. The amalgamation which he orchestrated reached a peak of sorts in 1917 when Southern California Edison acquired Pacific Light and Power Corporation, the

Ventura County Power Company, and Mt. Whitney Power and Electric Company (Hinson 1956:28-32), all of which provided new markets to justify the development of the Big Creek projects.

While Southern California Edison was expanding its geographic network outwards, its inner core was somewhat weakened. By the 1910s, Los Angeles was agitating for control over the city's own electricity, some of which was already being produced by hydro power along the Owens Valley aqueduct. This was part of a contemporary trend toward public or municipal ownership of electrical utility companies (Miller 1912). Increased state regulation of utility rates, inaugurated in March 1912, seemed to defuse this movement (Kennedy 1912:6; Myers 1991b:166-173; 176-177), but Los Angeles was still determined to have its own electrical utility. Negotiations between the city and Edison dragged on for years before Edison finally relinquished control over the city's lines in 1922 (Myers 1991b:162-164). At the very least, however, the Los Angeles Department of Water and Power was fully synchronized with the Edison network in 1917, with both systems operating at 50 cycles per second (Hinson 1956: Historical Notes; Rustebakke 1983:2).

In the 1920s and 1930s, the trend toward larger hydroelectric powerhouses coincided with the gradual abandonment of the smaller, less productive plants. Administratively, Big Creek and the other large plants in the Sierra were separated from the smaller plants within the so-called Eastern Division of Edison's Hydro Department. By the 1920s, the Operating Department was complaining that all of the older small hydro plants were showing signs of age and that maintenance costs were increasing as a result. Specifically, this entailed the substitution of steel flumes for wooden flumes and the need to repair penstock corrosion (Operating Department 1929). Even as the first Southern California Edison generating units went into operation at Hoover Dam in the late 1930s, small plants were being abandoned in the Eastern Division. It was around this time that the Pedley and Stone Castle plants were abandoned as economically infeasible. Ontario No. 2 was destroyed by the 1938 flood and was not rebuilt for many years (Hinson 1956:57-59; Myers, personal communication 1992).

This period also witnessed a reduction in personnel, first brought on by the introduction of semi-automatic powerhouse control in the 1920s and finally exacerbated by the financial woes and slow growth during the Great Depression of the 1930s. This situation continued right on through the early 1940s due to the shortage of manpower during World War II.

Between 1945 and 1948, Southern California Edison had to confront one of its greatest expenses, the general network-wide frequency change from 50 cycles to 60. The system had used 50 cycles since the days of the first three-phase generators at Mill Creek No. 1. With the exception of installations in the San

Joaquin Valley, the use of 50 cycles spread with the Edison distribution system. Unfortunately for Edison, the rest of the country had standardized to 60 cycles by the 1940s. With the growing interdependence of different networks, this anomaly had to be remedied. Even though this change-over often required the rewinding of electrical generators -- and the replacement of electric motors -- it has been estimated that the Edison system itself gained some 50,000 kw in generating capital, mostly in the steam plants (Hinson 1956:60).

From the introduction of semi-automatic control and steel flumes, to the reduction of manpower, to the rewinding of generators in the wake of the cycle change, many of the modifications to the Edison network between the 1920s and 1940s were manifested in the Santa Ana River hydroelectric system. It is the story of these alterations that will bring these powerhouses into the modern era.

Alterations to the SAR System, 1912-1980

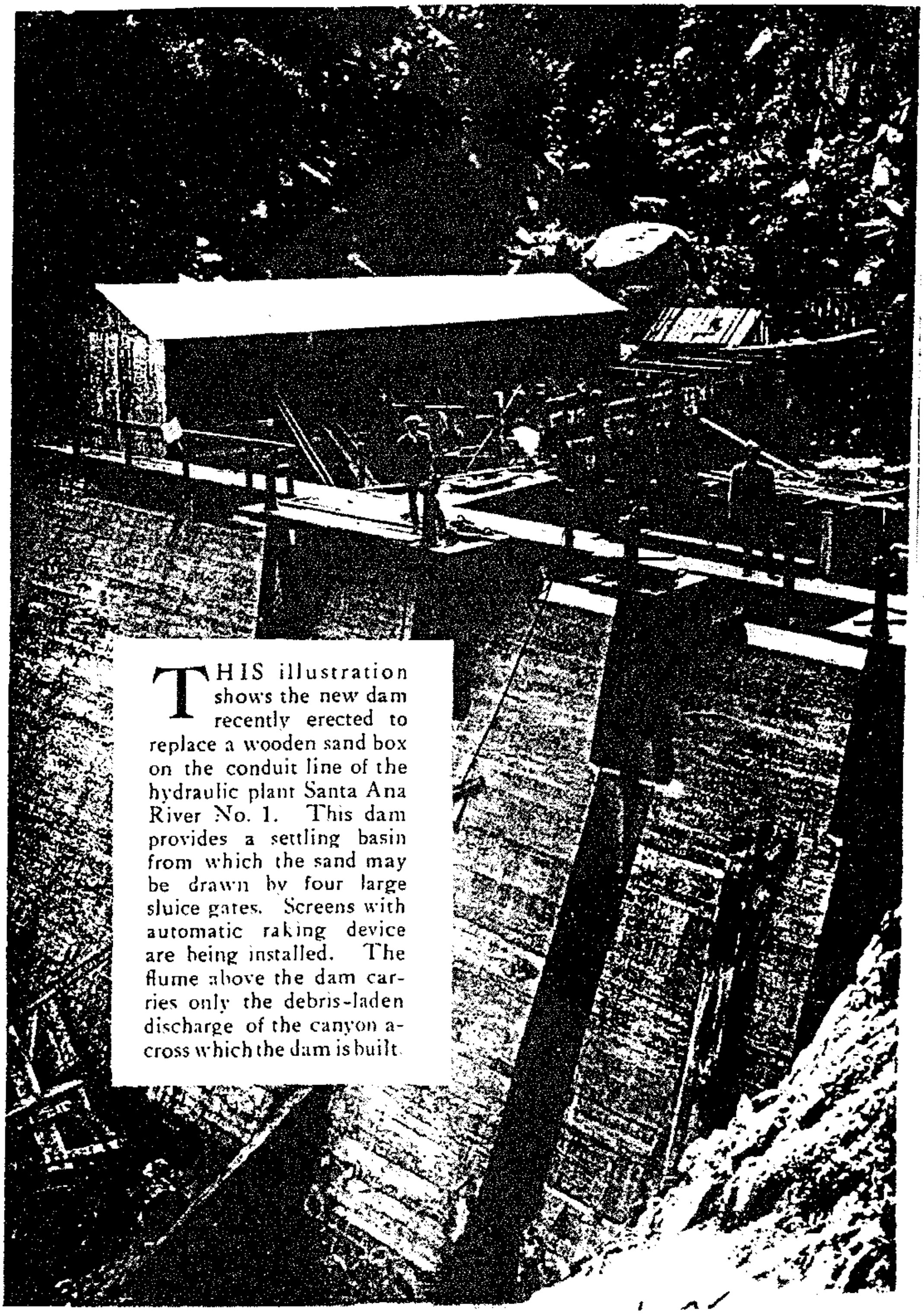
The alterations that have occurred to the Santa Ana River hydroelectric system since the 1910s have generally been in the nature of the replacement of wooden structures, improvements to wiring and other electrical equipment, and the addition of control devices. Most of the physical plants have not been altered, which is noteworthy for engineering structures built around the turn of the century.

Perhaps because SAR 1 was the oldest of the Santa Ana Canyon powerhouses, this plant was the first to have its wiring overhauled. With this came a whole series of changes to the Santa Ana system that also affected SAR 2 and (after 1917) SAR 3. In this section, the major alterations to each of the Santa Ana powerhouses are presented. System-wide changes are presented with the discussion of SAR 1, since it remained the nerve center of the system throughout most of this period. Changes specific to SAR 2 and 3 will be discussed in the sections which follow.

Alterations to SAR 1

Beginning in 1912, a series of changes took place at SAR 1 and along the general SAR transmission line, ranging from sandbox replacement to new steel towers. In 1912, the present machine shop and barn were constructed west and southwest of the powerhouse. The old wooden sandbox, located between Tunnels 3 and 4, was removed in 1912-1913, replaced by a large concrete structure that formed a dam across the small canyon of Breakneck Creek where the old sandbox used to be (Figure 28). The new structure created a chamber that served as a large sandbox; the dam itself had four sluice gates and six overfall weirs (Dennis 1914; Drawing 5787; Fowler 1923:591).

Figure 28. Concrete Sand Box, SAR 1, 1913
(*Edison Current Topics* 1913, back cover)



THIS illustration shows the new dam recently erected to replace a wooden sand box on the conduit line of the hydraulic plant Santa Ana River No. 1. This dam provides a settling basin from which the sand may be drawn by four large sluice gates. Screens with automatic raking device are being installed. The flume above the dam carries only the debris-laden discharge of the canyon across which the dam is built.

This construction appeared to have foreclosed for all time the plan for a permanent dam below the juncture of Bear Creek and the Santa Ana River.

This period also saw the beginning of work on a whole range of electrical changes to the powerhouse itself. In 1912, the first oil break switches were installed (Heard Over the High Line: From Redlands 1912). By 1914, the original SAR 1 marble switchboard had been replaced by the marble-paneled board that is still situated in the powerhouse immediately south of the generating units (*Edison Current Topics* 1914; CA-130-J-42 and CA-130-J-38). Along with the switchboard, the wiring was also overhauled in 1914 (Fowler 1923:593).

By 1913, the 12 original transformers had been replaced by six General Electric, Type W.C. transformers (*SAR 1*, 1909-1945). The six transformers were arranged in two banks of three each (CA-130-J-45). Unlike the earlier transformers which used air-blowers, these were water-cooled (Fowler 1923:593).

Perhaps the most momentous change to the system was the new transmission line between the Santa Ana Canyon and Los Angeles, which was begun in 1912. Even before this time, some of the wooden poles had been replaced by extra steel towers specifically designed for use on the Kern River in the early 1900s. These metal towers were modified farm windmill towers that were 40, 50, or 60 feet high. They were manufactured by the U.S. Wind Engine and Pump Company of Batavia, Illinois (SCE Corporate Documentation Center, Drawings E2737, E2739, and E2740, dated July and August 1905; White 1991:6). When the Santa Ana transmission line was completely overhauled in 1912 and 1913, all the wooden poles were replaced by these metal towers, or towers of a similar construction (CA-130-X-6).

The new transmission line was needed for a number of reasons. The original 1898-1899 line was designed to transmit electricity from the canyon to Los Angeles. By the 1900s, however, downtown Redlands was already drawing so much power that current often moved in the opposite direction. This necessitated a new line to accommodate the extra energy load demanded by the burgeoning cities in San Bernardino and Riverside counties (Dennis 1913:4). Since 1898, there had also been a number of innovations in the design and placement of insulators and the towers that supported them. By around 1907, at least part of the line between Colton and Los Angeles was equipped with Knowles No. 2600 brown ceramic insulators. These were much larger than the original Redlands type, with a long base and a distinctively broad petticoat (Myers, personal communication 1992). The original wooden pole line had insulators set upright on pins; the Knowles No. 2600 insulators were also set this way. By the 1910s, however, the more modern technique was to use steel towers with insulators turned downward and arranged in series (*Edison Current Topics* 1912c).

The changes also required a new method of transmission. The Santa Ana Canyon portion of the line, between SAR 1 and Colton, remained 33,000 volts. The new line had No. 1 copper cable, with steel towers set up every 45 feet (*Edison Current Topics* 1912a:16). An example of this new steel tower for the canyon is shown in Drawing 5821. Some of these towers are still in place between SAR 1 and 2 (Secord 1985:8:11).

The line between Colton and Los Angeles now carried a potential of 66,000 volts and was completely new; even the old Southern Pacific right-of-way was abandoned (Dennis 1913:4). The new steel towers had three cross-arms, each 14 feet long, from which were suspended six series of disk insulators for the line's two circuits. Vertical clearance between the wires was eight feet. The towers were 71 feet high, with a 14-foot square base at ground level. They were spaced 700 feet apart (*Edison Current Topics* 1912c).

In addition to the newly adopted steel towers, there were experimental towers along a seven-mile stretch across part of the Chino Ranch, at the request of the landowner. For this reason, the experimental towers were dubbed the "Chino Steel Poles." These were also 71 feet high, but only three feet square at the base, with large concrete foundations for stability (*Edison Current Topics* 1912c).

The new Colton substation controlled the voltage brought in from Los Angeles, as well as the energy generated along the Santa Ana River and Mill Creek. At the substation, the current, which now ran from Los Angeles to Redlands, was stepped down from 66,000 volts, as was the 33,000 voltage brought in from the Santa Ana plants. From the Colton substation, power left for local use on five circuits of 10,000 volts and two circuits of 33,000 volts (*Edison Current Topics* 1912b, 1912g).

It was around this time and certainly by 1913, that one of the four Pelton water wheels was replaced by a Doble wheel (SAR 1, 1909-1945). The new wheel had 21 buckets which were powered by water from a 5-inch needle nozzle (Fowler 1923:593).

It was also probably during this decade that one of the local Edison employees, Gustaf Clingwald, invented a governor-tripping device to regulate the water level in the forebay of the powerhouse (Secord 1985:7:12). Little is known about this device, even though a diagram of its workings has been preserved by a former Edison employee stationed in the canyon, Edward Van Zeyl.

The last sequence of changes to the powerhouse in the 1910s came in the wake of the 1916 flood. By that spring, there were almost 100 people working in the Santa Ana Canyon and at Mill Creek, repairing roads, flumes, tunnels, and headworks. It was at this time that a new steel tower high line was installed in the canyon (*Edison Current Topics* 1916:57; Drawing 4932).

A small landslide associated with the 1916 flood destroyed the original SAR 1 forebay, and it was not replaced. By Fowler's time, the lower end of Tunnel 18 was connected to a 44-inch diameter pipe that extended 851 feet to the site of the old forebay, where it was joined by a "Y" to two 30-inch pressure pipes that plunged down to the powerhouse (Fowler 1923:592). It was almost surely in the aftermath of the 1916 flood that the second pressure pipe was installed at SAR 1.

The biggest change to the SAR system in the 1920s was the advent of semi-automatic control in 1921. With this control in operation, the plants only had to be started up by operators and could then be left unattended for extended periods of time. This prompted a considerable reduction in the staff required to watch over the facilities in the canyon.

By 1924, SAR 1 had taken on much of its modern appearance with the two penstocks, the machine shop, and the barn (SAR 1 1909-1945). That was such a low water year that Edison tried a one-year experiment with a slight cut in frequency, from 50 to 49 cycles, as a power-saving measure (Coble, personal communication 1992). It is not known whether this stratagem proved successful, and it may simply have been unintentional due to the low volume of water carried in the system (Myers, personal communication 1992).

The big change of 1925-1926 was the replacement of the wooden flumes throughout most of the SAR conduit system, and certainly at SAR 1 and 3. The old flumes were replaced with steel (see Appendix: Large Format Engineering Drawings, SAR 1, No. 11-28; SAR 2, No. 7-28; CA-130-G-6). At least a few of these new flumes were destroyed in the flood of February 1927 and had to be rebuilt. A diversion wall 110 feet long was then built above the SAR 1 intake to protect the intake flume and the cottage. Just below SAR 1, on the SAR 2 conduit system, about 85 feet of the siphon across the river had to be replaced, and a concrete retaining wall was built to protect this pipe. In the wake of the 1927 flood, it was noted that all the metal flumes throughout the SAR system were wearing on the bottom due to sand abrasion. This led to the addition of metal strips between 16 and 20 inches wide along the inside base of the flumes (Operating Department 1927).

In 1929, SAR 1 switched from semi-automatic to automatic control (Operating Department 1929). It is not known exactly what mechanical changes were entailed, but it continued the trend toward a reduced staff in the Santa Ana Canyon.

The staff reduction was further accelerated by the Great Depression of the 1930s which necessitated a sizable retrenchment in the Edison system. There were various moves throughout the

1930s to decrease the number of employees (Operating Department 1931, 1934). By 1931, there were no more boardinghouses in the Santa Ana Canyon (Operating Department 1931), and the 1930s saw the removal of many of the original workers' quarters and related buildings (Operating Department 1936; Secord 1985:7.7). By 1937, there were only 69 employees in the entire Southern Division (the former Eastern Division) of the Edison network (Operating Department 1937).

Renewed flooding in 1938 brought another flurry of activity to the canyon, but the early 1940s saw a return to the policy of low expenditure and limited manpower as a result of World War II. In 1943, new equipment was installed at SAR 1 so that the powerhouse could be operated as an "unattended semi-automatic station" (Operating Department 1943). Exactly how this differed from the semi-automatic and automatic controls implemented in the 1920s is not known.

In 1945, plans of the whole SAR system had to be prepared for the Federal Power Commission (see Appendix: Large Format Engineering Drawings, SAR 1, No. 34-43). The drawings of the SAR 1 intake indicated that there were still two dams, one on the Santa Ana River and the other on Bear Creek. The latter had the SAR 1 conduit intake. A tunnel (Tunnel 0) connected the reservoir on the Santa Ana River with that at Bear Creek (Drawing 523191). It seems likely that this tunnel was built in the wake of the 1938 flood; it is still in use today. The conduit flumes were described as the Lennon-type of steel flume, comprised of a half-circle with a radius of 3.5 feet (Drawing 523196). The SAR 1 powerhouse complex itself contained the powerhouse, the store building (later known as the machine shop), switchrack, barn, a well and pumphouse belonging to the Bear Valley Mutual Water Company, and four houses identified by the letters G, I, L, and N (Drawing 523690; CA-130-51).

The most drastic change took place in the late 1940s, when Southern California Edison switched from 50 to 60 cycles. The switch had been presaged by a cycle test that took place in June 1940. At that time, the generators at SAR 1 and 2 and Mill Creek 2 and 3 were switched to 60 cycle production. To enable the 60-cycle power to enter a comparable grid, a temporary connection was made between Mill Creek and facilities of the Nevada-California Electric Corporation. As a result of this test, it was discovered that the SAR units produced less at 60 cycles than at the original setting of 50 (Operating Department 1940).

After World War II, Southern California Edison was ready to make the switch to 60 cycles. According to Edison's internal records, all of the plants in the Southern Division, except those in the San Antonio Canyon, were converted to 60 cycles in 1947. Specifically, SAR 1, 2, and 3 were converted in February of that year (Operating Department 1947). In order to improve the efficiency of the powerhouses at 60 cycles, the generators at SAR

1 were rewound in the two years that followed (Operating Department 1949).

Full automation came to the SAR system in 1958, when the present automation devices were installed (Secord 1985:7.12). Other changes took place in the 1960s. The SAR 1 marble switchboard was abandoned around 1960, when the modern switchboard was installed in the northwest corner of the powerhouse, where it is located today. The transformers were also replaced, with the new models positioned outside. The water-driven exciters, which had been used periodically throughout the 1950s, were finally disconnected. In the 1960s, the Seymore transmission line was installed between SAR 1 and Snow Valley (Van Zeyl, Hair, personal communications 1992). The SAR 1 headworks cottage was demolished around 1980; the other houses immediately adjacent to the powerhouse were already long gone (Hair, personal communication 1992).

Today, the intake of SAR 1 is much the same as it was depicted in the 1945 plans for the Federal Power Commission. Both the Santa Ana River and Bear Creek are dammed just above their confluence. Both dams are made of concrete. The Santa Ana River dam is relatively narrow and high (CA-130-A-1); the Bear Creek dam is relatively long and low (CA-130-B-4). Both dams are equipped with gates on the northwest side, which are opened only when water has to be diverted out of the reservoirs. Adjacent to the gates, again on the northwest side, are the outlets. The Santa Ana reservoir outlet passes through a grate to enter Tunnel 0, which cuts through the rocky spur that separates the two reservoirs. Tunnel 0 then empties into the Bear Creek reservoir (CA-130-B-1). Together, Santa Ana River and Bear Creek waters then exit the Bear Creek reservoir through another grate into the conduit, which is situated on the northwest side of the Santa Ana River valley. Passing through a short series of pipes, concrete canals, and a fish screen, the conduit water then enters Tunnel 1. Finally, between Tunnels 3 and 4, at Breakneck Creek, the water enters the concrete sandbox that was built in 1912-1913 and is still in use today (CA-130-F-1).

Alterations to SAR 2

The first substantial alterations to the SAR 2 powerhouse probably did not occur until the aftermath of the 1916 flood when the grounds around the powerhouse were landscaped. About 10 years later, the Bennett Surge lightning arrester was installed outside the plant. The following year, in 1927, the new transformers were set up just outside the powerhouse, rather than inside, where they had originally stood (Coble, personal communication 1992). The lay-out of the powerhouse and its auxiliary buildings during this period has been preserved on two maps, dating from 1924 and 1928 (SAR 2, 1909-1945).

The 1930s saw additional work to the SAR 2 conduit system. The Santa Ana Well No. 1 was dug near SAR 1 in 1930. This was a wood-lined well, 105 feet deep, designed to catch groundwater running below the river bed and pump it into the SAR 1 tailrace for use by both SAR 2 and 3 (Hornbeck and Botts 1988:20). In 1935, suspension cables were added to support the 10-inch diameter pipeline from Alder Creek to the main conduit line. With this installation, the Alder Creek pipe became a permanent fixture of the SAR 2 conduit (Operating Department 1935). In 1939, the old governors for the two water wheels were replaced by Woodward governors (Operating Department 1939).

In the late 1940s or possibly later, the Unit 1 Doble water wheel was rebuilt by the Pelton Water Wheel Company to operate better at the speed required for 60 cycles. The Unit 2 Doble wheel was not significantly altered (Fryer 1980:35; Secord 1985:7.11). By around 1950, the last of the houses associated with the SAR 2 powerhouse were demolished (Coble, personal communication 1992). The powerhouse setting itself had been greatly altered since the early days of the twentieth century. The 1916 and 1938 floods had filled the building with mud and debris, and the accumulation had been even greater in the areas outside. When SAR 2 was first constructed, the building was situated above the surrounding terrain; by mid-century, the powerhouse was actually below the surrounding surface (Secord 1985:7.7).

Alterations to SAR 3

The first alterations to SAR 3 took place before Edison's acquisition of the plant in 1917. These have already been discussed in the initial treatment of SAR 3, then known as the Mentone plant. Just as many changes took place after Edison's acquisition. In fact, the greatest modification to any of the SAR plants occurred at SAR 3 in the late 1940s, when the original impulse water wheel was replaced by a reaction turbine water wheel. This was the only turbine ever installed in the SAR system.

By 1917, the powerhouse transformers had already been transferred outside, to the lean-to described by Fowler (1923:598). Most of the changes to the powerhouse vicinity in the 1920s were to the auxiliary buildings. In 1922, the shop building was smaller and closer to the powerhouse than it would be in 1928 (Drawings 42993, 48833). Also, the switchrack was not depicted in the 1922 plan, but did appear for the first time in 1928. Otherwise, the auxiliary buildings remained the same throughout the 1920s: the powerhouse, the shop, three cottages, a boardinghouse, and a barn (Drawing 48833).

The 1920s and 1930s saw the replacement of wooden flumes with Lennon steel flumes and metal supports. A 90-foot well was dug in 1930 adjacent to the SAR 2 tailrace to augment the water supply for

SAR 3. This well was identified as the Santa Ana No. 2 Shaft (Hornbeck and Botts 1988:21; Secord 1985:7.13).

In 1935, SAR 3 was equipped with relays, alarms, and other control equipment that allowed the plant to operate as an "unattended semi-automatic station." With this development, all of the Edison stations, except those at Big Creek, now functioned on a semi-automatic or automatic basis (Operating Department 1935). In 1939, the Lombard governor on the generating unit was replaced by a Woodward governor (Operating Department 1939).

In 1947, probably on the occasion of the cycle change, the original double-runner water wheel and two-phase generator at SAR 3 were replaced by a three-phase generator and reaction turbine, taken out of the Kaweah No. 2 plant. It was noted in the records that all other SAR 3 station equipment was replaced at this time (Operating Department 1947). At the time of its replacement, the old two-phase generator was the last of its kind in the entire Southern California Edison system (Hinson 1956:61-62).

The new reaction turbine was rated at 2250 horsepower, and was direct-connected to the three-phase generator rated at 1200 kw. The new water wheel was a Pelton-Francis Turbine made by the Pelton Water Wheel Company (Drawing 523126-1). This was a scroll-type turbine wheel, where water traveled through the water-tight wheel casing, entering at the periphery of the wheel and exiting the turbine from the center of the wheel. The wheel is turned as water is pushed against the 16 vanes attached to the wheel (Hair, personal communication 1992). The generator was a General Electric Alternating Current Generator, Type ATB, Class 10-1500-720, Form S, rated at 2300 volts, 1200 kilowatts, 377 amperes, and a speed of 720 rpm. This equipment had been made in 1905 for the Kaweah No. 2 plant (Hamilton, personal communication 1992). The new exciter was an Electric Generator, Type MP, made by General Electric. The new generating unit created power at 2400 volts, which was then stepped up to 33,000 volts by the transformers outside (Fryer 1980:28).

The switchboard and the transformers were changed in 1947, but it is not known if they are the ones present today. The existing transformer is a No. 1 Bank, 2.4/33 kv Wagner Transformer, located along the outside of the south wall of the powerhouse. The lean-to described by Fowler in 1923 no longer exists.

In addition to these changes to the electrical system, most of the frame auxiliary buildings were demolished in the 1930s and 1940s. Those structures included the three houses or cottages, the boardinghouse, and the barn (Secord 1985:7.8). Most of the outbuildings now present at SAR 3 appear to date from the late 1950s and early 1960s, or were moved into place about that time. These modern facilities consist of an administrative office, a warehouse and carpenter shop, a vehicle service yard, a storage building, and a storage garage (CA-130-29).

Additional Lennon flume work was done to the conduit system in 1956, including the High Lennon flume over Warm Springs Canyon (see Appendix: Large Format Engineering Drawings, SAR 3, No. 47-48). The SAR 3 forebay area also took final shape in 1956, with a 40-inch diameter penstock pipe, a 36-inch spillway pipe, and a flume to the "Greenspot Diversion Canal" operated by the Bear Valley Mutual Water Company (Drawing 541725).

10. CONCLUSION

The Santa Ana River hydroelectric system occupies a unique niche in the history of commercial electrical generation in both southern California and the whole United States. This is particularly true for Santa Ana River Powerhouse 1, which was completed in 1898 and went on line in early 1899. At the time it was completed, SAR 1 had the longest transmission line in the United States, and quite possibly the largest hydroelectric generators in the world. A number of features were employed at SAR 1 that would later become standard in the generation of hydroelectricity. Foremost of these were individual tail races, internal revolving field alternators, and the transposition of wires along the transmission line.

Many of the other features, though outdated today, were significant engineering achievements in 1898. These included the tunnel and flume work of the conduit system, the impulse Pelton water wheels, the 82-83 mile transmission line with its "Redlands" ceramic insulators, and the very size and audacity of the project. When SAR 2 and 3 were added to this system in the early 1900s, it became the prototype for even larger hydroelectric projects in the Sierra Nevada, constructed throughout the 1910s and 1920s.

By the early 1930s, the Santa Ana River powerhouses had already been surpassed as state of the art hydroelectric facilities. Due to semi-automatic and automatic controls, the powerhouse communities in the Santa Ana Canyon had been in decline for 10 years. Were it not for the fact that they were remarkably efficient, it is unlikely that they would have been maintained in operation. All of this is recounted to emphasize how rapidly electrical generation equipment and transmission systems evolved in the early years of the twentieth century in response to the increasing demands for power.

The Santa Ana River hydroelectric system was nominated to the National Register of Historic Places by Paul Secord in 1985 (Secord 1985). A number of cultural resource management projects, surveys, test excavations, and reports followed, many conducted by Greenwood and Associates under the auspices of the U. S. Army Corps of Engineers. Most could not be recapitulated in this report, but some of the most relevant ones should be mentioned. A study of the Santa Ana Canyon Road was conducted in 1987 (Hatheway 1987). The following year, a synthesis of the various agricultural and hydroelectric water systems in the Santa Ana Canyon was developed (Hornbeck and Botts 1988). At that time, Powerhouses 1 through 3 were tentatively recorded as archaeological sites: SAC-2, SAC-10, and SAC-26, respectively. A report on some of the work camps utilized during the construction of the Santa Ana River powerhouses also appeared in 1988, following test excavation at CA-SBR-5500H associated with SAR 1 (Foster et al. 1988). That report was followed by a more detailed examination of operator housing in the Santa Ana River Canyon, concentrating on the outbuildings at SAR 2. As a result of this research, the housing area on the hill above Powerhouse 2 was recorded as archaeological site CA-SBR-5502H (Foster et al. 1989). In addition to these studies which are primarily historical and archaeological, the Santa Ana River hydro system has been designated an Historic and Engineering Landmark by the American Society of Civil Engineers, Los Angeles Chapter (Foster et al. 1989:1).

For all of these reasons, it has been important to report the history and original condition of the facilities, catalog the changes that have been made over nearly a century, as well as document the current state of the system before it is impacted by the construction of the Seven Oaks Dam, which has already been inaugurated by the Los Angeles District of the U.S. Army Corps of Engineers. The Seven Oaks Dam is part of the Army Corps' on-going program of flood control along the Santa Ana River.

The Seven Oaks Dam site is located between SAR 2 and SAR 3 within the Santa Ana River canyon. Upon completion, the dam will serve as a flood control structure. The flood water impound area includes the site of the SAR 2 powerhouse, which will be abandoned after the first incidence of flooding. Even though it is not now anticipated that there will be direct impacts to SAR 1 and 3, this report is a study of all three powerhouses in their present setting, since they constitute a meaningful and cohesive complex.

When Thomas Edison died on 18 October 1931, serious consideration was given to the idea of honoring his memory and his unparalleled electrical achievements by shutting down all electrical current across the country for one full minute. President Hoover finally decided that even this small gesture would be too risky to the nation's economy, already stressed by the Great Depression (Myers 1991b:394). In fact, Edison's memory was perhaps even more honored by the realization that the electric current that he helped popularize and spread could not be spared for even one instant. By the 1930s, commercial electricity was already indispensable. Today, it is even more so.

The development of electricity since the mid-1870s has been nothing short of extraordinary, and it has changed the nation's way of life perhaps more than any other single development perfected during the Second Industrial Revolution of the late 1800s. Unlike perhaps some other results of that era, the development of electricity has been positive and constructive, opening up possibilities for inventions, technologies, and amenities beyond imagination in 1900. Electricity has provided much of the force needed to bring new options within reach of both industry and the individual consumer.

The first chapters in the history of electrical development may have been written in Europe and the northeast United States, but subsequent chapters have been written in southern California. This is especially true in the development of the Southern California Edison Company and its predecessors. Among these chapters, at least one could be devoted to the development of the Santa Ana River hydroelectrical system, which was in the forefront of electrical engineering during the critical years between 1898 and 1904. While this was not a long period of time, no other electrical installation has had a similarly eminent position that was much longer or an influence more pervasive. The Santa Ana system, and Santa Ana River No. 1 in particular, paved the way for the development of Kern River, Big Creek, and even Hoover Dam.

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1904 External Elevations, Power House Santa Ana River No. 2, Edison Electric Co., Nov. 3, 1904. On file, No. 5392 (former number 2445-23), Southern California Edison, Rosemead.

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1945 Bear Creek and Santa Ana River Diversion Dams and Concrete Conduit No. 1, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523191 (Sheet No. 1; for filing with Federal Power Commission), Southern California Edison, Rosemead.

Drawing 523196
1945 Details of Steel Flume, Typical Bents and Trusses, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523196 (Sheet No. 6; for filing with Federal Power Commission), Southern California Edison, Rosemead.

Drawing 523690
1945 Intake and Power House Areas, Santa Ana No. 1; Detail Map of Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523690 (Sheet No. 5; for filing with Federal Power Commission), Southern California Edison, Rosemead.

Drawing 523856-2
1945 Crane Runway for 5-Ton Push Type Crane, Santa Ana River O. 3, Sept. 4, 1945. On file, No. 523856-2, Southern California Edison, Rosemead.

Drawing 541725
1956 Tailrace and Forebay, Santa Ana No. 3, Exhibit L, Jan. 25, 1956 (Sheet 6; for filing with Federal Power Commission). On file, No. 541725, Southern California Edison, Rosemead.

Drawing 541728
1956 Intake Flume and Tunnel Sections, Santa Ana No. 3, Exhibit L, Jan. 25, 1956 (Sheet 1; for filing with Federal Power Commission). On file, No. 541728, Southern California Edison, Rosemead.

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Appendix

List of Engineering Drawings at Southern California Edison

List of Engineering Drawings at Southern California Edison. Blue Line Reproductions, Small Format (22 by 34 inches), Selected by William Myers and Laura Martin, October 1991:

General

1. Road Location from Power House No. 3 to Intake of Power House No. 1, Santa Ana Hydro Project, June 3, 1942. Survey by J.H. Dickens. 1942. On file, No. 413100, Southern California Edison, Rosemead.

2. Southern California Edison Company Ltd. Santa Ana Plants Nos. 1, 2 and 3 (no date). On file, No. 428141-0, Southern California Edison, Rosemead.

3. Southern California Edison Company Ltd. Santa Ana Plants Nos. 1, 2 and 3, Map Showing Points of Diversion, Spill and Use (no date). On file, No. 428142-0, Southern California Edison, Rosemead.

Santa Ana River Power House No. 1

1. Gate Valve (24 inch) Between Small Forebays at Head of Pipe Lines, Southern California Power Co., Sept. 2, 1898. Location: Santa Ana No. 1; Drawn by OHE. On file, No. 4269 (former number 1464-18), Southern California Edison, Rosemead.

2. Special Ells and Y Piece, Edison Electric Co., Jan. 5, 1908. Location: SAR 1; Drawn by W.R.B.. On file, No. 4440 (former number 3319-20), Southern California Edison, Rosemead.

3. Needle and Nozzle Tip, Santa Ana No. 1, Southern California Edison Co., Apr. 28, 1910, revised May 12, 1910. Drawn by R.J.C.W. On file, No. 4500 (former number 3690-20), Southern California Edison, Rosemead.

4. Outline of Needle and Ring for Pelton Water Wheel, Santa Ana River No. 1, Apr. 22, 1912. Drawn by W.M.B. On file, No. 4667 (former number 4726-19B), Southern California Edison, Rosemead.

5. Plan, Elevations and Sections of Storehouse-Shop Building: Building for Storehouse, Blacksmith Shop, Etc., of S.A.R. No. 1, May 29, 1912. Drawn by F.G.M. On file, No. 4673 (former number 4739-19B), Southern California Edison, Rosemead.

6. Plan, Elevations and Sections of Stable, Santa Ana No. 1, May 29, 1912. Drawn by F.G.M. On file, No. 4674 (former number 4740-19B), Southern California Edison, Rosemead.

7. Revolving Fish Screen, S.A.R. No. 1. Feb. 19, 1914. Drawn by

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8. Flume Replacement. 1926, Additional Truss Bracing. Santa Ana River No. 1, Apr. 24, 1926. On file, No. 45567, Southern California Edison, Rosemead.

9. Addition to Sides of Steel Transitions, Santa Ana River No. 1, Nov. 1926. On file, No. 46083. Southern California Edison, Rosemead.

10. Sluice Gate for Rock Drop, Santa Ana River No. 1, Jan. 10, 1925. Drawn by McC. On file, No. 47523, Southern California Edison, Rosemead.

11. Governor Oil Tanks, Santa Ana River No. 1, Mar. 8, 1926; Three-Foot Diameter Tank removed, Mar. 20, 1926. On file, No. 47908, Southern California Edison, Rosemead.

12. Timber Bridge for Forebay Road, Santa Ana River No. 1, Apr. 30. 1929. On file, No. 49044, Southern California Edison, Rosemead.

13. Nozzle Tip for Unit No. 4. Santa Ana R. No. 1, Nov. 8. 1933. On file, No. 411666-1, Southern California Edison, Rosemead.

14. Nozzle Needles for Units 1, 2, and 3, Santa Ana River No. 1, May 7, 1934. On file, No. 411721-0, Southern California Edison, Rosemead.

15. Split Yoke for Gate Lifting Mechanism. Santa Ana River No. 1, Nov. 8, 1934. On file, No. 411773-0. Southern California Edison, Rosemead.

16. Nozzle Tip for Units Nos. 1. 2, and 3, Santa Ana River No. 1, Dec. 4, 1936. On file, No. 411919-0, Southern California Edison, Rosemead.

17. 48-Inch Pipe Replacing Flume No. 8, 1937, Santa Ana River Plant No. 1, Aug. 13, 1937. On file, No. 412031-0, Southern California Edison, Rosemead.

18. Camp Water, Fire, and Sewer Pipe Lines, Santa Ana River No. 1, Oct. 14, 1940. On file, No. 412864-0, Southern California Edison, Rosemead.

19. Wiring Diagram of Semi-Automatic Controls and Alarms (for Construction), S.A.R. No. 1, May 9, 1945. On file, No. 413589, Southern California Edison, Rosemead.

20. Miscl. Foundation Details, Santa Ana No. 1 Hydro Plant, Oct. 8, 1958. On file, No. 428056-0, Southern California Edison, Rosemead.

21. Elect. Equip. Sections, Powerhouse, Santa Ana No. 1 Hydro Plant, Sept. 29, 1958; Revised Bus Supports, Jan. 28, 1959. On file No. 428057-1, Southern California Edison, Rosemead.

22. Three-Line Wiring Diagram, 33 KV and No. 1 Trans Bank, Santa Ana No. 1 Hydro-Plant, Oct. 27, 1958; Record Revisions, July 12, 65. On file, No. 428058-1, Southern California Edison, Rosemead.

23. Wiring Diagram, DC Panel and Batt. Charger, Santa Ana No. 1 Hydro Plant, Oct. 27, 1958. On file, No. 428059-0, Southern California Edison, Rosemead.

24. Elec. Equipment Sections, 33 KV Switchrack, Santa Ana No. 1 Hydro-Plant, Oct. 6, 1958. On file, No. 428061-0, Southern California Edison, Rosemead.

25. Elec-Equipment Plot Plan, Santa Ana No. 1 Hydro Plant, Oct. 10, 1958. On file, No. 428615-0, Southern California Edison, Rosemead.

26. Wiring Diagram, 2.4 KV Switchgear Synch. Panel, Santa Ana No. 1 Hydro Plant, Oct. 27, 1958. On file, No. 428649-0, Southern California Edison, Rosemead.

27. One Line For Operation, Santa Ana No. 1 Hydro Plant, Sept. 22, 1975. On file, No. 455475-5, Southern California Edison, Rosemead.

28. Forebay Rake, Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455659-0, Southern California Edison, Rosemead.

29. Automatic Water Control Needle Detail Units Nos. 1, 2 and 3, Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455662-0, Southern California Edison, Rosemead.

30. Steel By-Pass Flume, S.A.R. No. 1 Sand Box, Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455664-0, Southern California Edison, Rosemead.

31. Wiring Diagram, S.A.R. No. 2-3 Line 33 KV P.C.B., Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455666-0, Southern California Edison, Rosemead.

32. Worm Gear Assembly for Machining Water Wheel Centers, Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455668-0, Southern California Edison, Rosemead.

33. Wiring Diagram Seymore 33 KV Line, Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455672-0, Southern California Edison, Rosemead.

34. Differential Control Details for Leaf Rake, Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455679-0, Southern California Edison, Rosemead.

35. Forebay Rake, Santa Ana River No. 1. Jan. 24, 1977. On file, No. 455681-0 Southern California Edison, Rosemead.

36. 41 Flume Truss Transition Flume No. 10, Santa Ana River No. 1 Jan. 24, 1977. On file, No. 455682-0, Southern California Edison, Rosemead.

37. Switchrack Gusset and Steel Layout Detail, Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455684-0, Southern California Edison, Rosemead.

38. Forebay Rake, Santa Ana River No. 1, Jan. 24, 1977; Revisions, May 5, 1977. On file, No. 455685-1, Southern California Edison, Rosemead.

39. 33 KV Switchrack Framework, Santa Ana River No. 1, Jan. 24, 1977. On file, No. 455687-0, Southern California Edison, Rosemead.

Santa Ana River Power House No. 2

1. Section, Power House, Santa Ana River No. 2, Edison Electric Co., Nov. 15, 1904. Location: SAR 2; Drawn by F.P. Beach. On file, No. 4330 (former number 2448-19), Southern California Edison, Rosemead.

2. Amended Drawing of Standpipe, Curve and Taper, Santa Ana River Power Plant No. 2 of the Edison Electric Co., Approved May 12, 1904. F.C. Finkle, Chief Hydraulic Engineer. On file, No. 4527 (former number 3866-71), Southern California Edison, Rosemead.

3. Preliminary Arrangement of Housing for 800 HP Water Wheel Unit for Santa Ana River Plant No. 2, Abner Doble Co. Engineers, June 7, 1904. Traced from Abner Doble Co. Blue Print No. 1663 (SCE Co. No. E-1458); Traced by E.P., Sept. 6, 1911. On file, No. 4611 (former number 4402-19B), Southern California Edison, Rosemead.

4. Water Wheel Governor Shaft Coupling, S.A.R. No. 2, June 19, 1913. Drawn by J.W.A. On file, No. 4725 (former number 5894-20B), Southern California Edison, Rosemead.

5. Switch Tower at Junction of S.A.R. Nos. 1 and 2 Transmission Lines, S.A.R. No. 2, Mar. 7, 1916. Drawn by F.H.M. On file, No. 4932 (former number 8710-7A), Southern California Edison, Rosemead.

6. Boring Rig for Reaming Bucket Bolt Holes of Water Wheels, Santa Ana River No. 2, Oct. 22, 1936. On file, No. 411848-0, Southern California Edison, Rosemead.

7. Additional Span to Bridge at No. 2 Plant, Santa Ana No. 2, July 28, 1937. On file. No. 412024-0, Southern California Edison, Rosemead.

8. Details of Code Discs, Hubs and Spacers for Alarm Coding Device, Santa Ana P.H. No. 2 and Mill Creek Nos. 2 and 3. Oct. 17, 1946. On file. No. 414316-0. Southern California Edison. Rosemead.

9. Three Line Wiring Diagram. Santa Ana River No. 2, Mar. 17, 1952. On file, No. 419809-0, Southern California Edison, Rosemead.

10. Switchboard Wiring Diagram Panel No. 1, Santa Ana River No. 2, Mar. 17, 1952. On file, No. 419810-0, Southern California Edison, Rosemead.

11. Switchboard Wiring Diagram Panel No. 2, Santa Ana River No. 2, Mar. 17, 1952; Changes, Apr. 8 and 23, 1971. On file, No. 419811-2, Southern California Edison, Rosemead.

12. Switchboard Wiring Diagram Panel No. 3, Santa Ana River No. 2, Mar. 17, 1952; Changes. Apr. 8. 1971. On file, No. 419812-1. Southern California Edison, Rosemead.

13. Switchboard Wiring Diagram Panel No. 4, Santa Ana River No. 2, Mar. 17, 1952. On file, No. 419813-1, Southern California Edison, Rosemead.

14. Switchboard Wiring Diagram Panel No. 5, Santa Ana River No. 2, Mar. 17, 1952. On file, No. 419814-1, Southern California Edison, Rosemead.

15. Switchboard Wiring Diagram Synchronizing Panel. Santa Ana River No. 2, Mar. 17, 1952. On file, No. 419870-0, Southern California Edison, Rosemead.

16. Conduit Details, Santa Ana River No. 2, Dec. 11, 1951; Changes, Dec. 14, 1951. On file. No. 419895-1. Southern California Edison, Rosemead.

17. Wiring Diagram, S.A.R. No. 1-3, Line 33 KV P.C.B., Santa Ana River No. 2, Jan. 24, 1977. On file. No. 455660-0, Southern California Edison, Rosemead.

18. Automatic Water Control Selsyn Restoring Mechanism. Santa Ana River No. 2, Jan. 24, 1977. On file, No. 455661-0, Southern California Edison, Rosemead.

19. Automatic Water Control Motor Drive for Needles Construction Details, Santa Ana River No. 2. Jan. 24, 1977. On file, No. 455667-0. Southern California Edison. Rosemead.

20. New BCB and Lightning Arrester Arrangement, Santa Ana River No. 2, Jan. 24, 1977. On file, No. 455670-0, Southern California Edison, Rosemead.

21. Switchboard Wiring Diagram, Panel No. 4, Santa Ana River No. 2, Jan. 24, 1977. On file, No. 455671-0, Southern California Edison, Rosemead.

Santa Ana River Power House No. 3

1. General Plot Plan, S.A.R. No. 3, Apr. 27, 1922. Drawn by R.E.K.; Traced from drawing by R.E. Keyser. On file, No. 42993 (former number 24656-460), Southern California Edison, Rosemead.

2. Flume Replacement, 1925-26, Consolidated Sheet List, Santa Ana River No. 3, Feb. 23, 1926. On file, No. 45342. Southern California Edison, Rosemead.

3. Flume Replacement, 1925-26, Bent Plates, Santa Ana River No. 3, Apr. 6, 1926. On file. No. 45520, Southern California Edison, Rosemead.

4. Reconstruction of Forebay, 1926 Flume Replacement. Santa Ana River No. 3, Apr. 27, 1926. On file, No. 45570, Southern California Edison, Rosemead.

5. Flume Replacement, 1926, Splice Plates for 99-Foot Spans on Warm Springs Trestle, Santa Ana River No. 3. May, 13. 1926. On file, No. 45597, Southern California Edison. Rosemead.

6. Conduit and Ground Bus Plan for Outdoor 30 K.V. Rack, Santa Ana River No. 3. Apr. 17, 1925, Plot Plan and Section E-E Added. May 25. 1925. On file, No. 47595, Southern California Edison, Rosemead.

7. Brackets for Transformer Rack, Elevation and Section of Steel, Santa Ana River No. 3, Oct. 27, 1927; Holes for Insulators Relocated, Nov. 12, 1927. On file. No. 48342. Southern California Edison. Rosemead.

8. Plot Plan, As Prepared for Property Data Book, Santa Ana River P.H. No. 3, Apr. 3, 1928. On file, No. 48833 (this drawing supercedes No. 15320), Southern California Edison, Rosemead.

9. Tail Race Baffles for Water Wheel, Santa Ana River No. 3, Dec. 28, (illegible; possibly 1928). On file, No. 49421, Southern California Edison, Rosemead.

10. Repairs, No. 1 to 2 Flume, Santa Ana No. 3, July 15, 1937. On file, No. 412008-0, Southern California Edison, Rosemead.

11. Elevation of Relay and Control Switchboard, Santa Ana River P.H. No. 3, June 23, 1943; Miscellaneous Changes, Mar. 14, 1945. On file, No. 413187-1, Southern California Edison, Rosemead.

12. Three Line Wiring Diagram for Generator and 33 K.V. Equipment, Santa Ana River P.H. No. 3, June 23, 1943: Miscellaneous Changes, Mar. 14, 1945. On file, No. 413188-1, Southern California Edison, Rosemead.

13. Three Line Wiring Diagram of Relay and Control Switchboard, Santa Ana River P.H. No. 3, June 23, 1943; Misc. Changes, Mar. 14, 1945; Rec. Rev.-Added IAV in Grd Detector Ckt, May 10, 1977. On file, No. 413189-2, Southern California Edison, Rosemead.

14. Elevations at Various Points from S.A.R. No. 3 Forebay Back to Approx. 640 Ft. up from Exit of "Long Tunnel," Mar. 1943. On file, No. 413545, Southern California Edison, Rosemead.

15. Exciter Drive Extension, Turbine from Kaweah No. 2 - Superceding Drwg. 413607, Santa Ana River No. 3 Power Hse., July 9, 1946. On file, No. 414159-0, Southern California Edison, Rosemead.

16. Switchboard Panels for 33 KV P.C.B. Control, Santa Ana River No. 3, Jan. 24, 1977. On file, No. 455663-0, Southern California Edison, Rosemead.

17. 33 KV Switch Rack Three Line Diagram for Construction, Santa Ana River No. 3, Jan. 24, 1977. On file, No. 455665-0, Southern California Edison, Rosemead.

18. 33 KV Control Panel, Santa Ana River No. 3, Jan. 24, 1977: Revisions, Mar. 29, 1989. On file, No. 455674-1, Southern California Edison, Rosemead.

19. Shaw Box 5 Ton Crane, Santa Ana River No. 3, Jan. 24, 1977. On file, No. 455678-0, Southern California Edison, Rosemead.

20. Bearing Cooling Water, Santa Ana River No. 3, Jan. 24, 1977. On file, No. 455686-0, Southern California Edison, Rosemead.

List of Engineering Drawings at Southern California Edison. Blue Line Reproductions, Large Format (30 by 42 inches), Selected by William Myers and Laura Martin, October 1991.

General

1. Santa Ana River Canyon Tower Line, Santa Ana River Canyon, Dec. 22, 1913. Drawn by W.H. On file, No. 5821 (former number 6580-31), Southern California Edison, Rosemead.

2. Detail Map of Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523686 (Sheet No. 1; for filing with Federal Power Commission), Southern California Edison, Rosemead.

3. Detail Map of Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523687 (Sheet No. 2; for filing with Federal Power Commission), Southern California Edison, Rosemead.

4. Detail Map of Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523688 (Sheet No. 3; for filing with Federal Power Commission), Southern California Edison, Rosemead.

5. Detail Map of Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523689 (Sheet No. 4; for filing with Federal Power Commission), Southern California Edison, Rosemead.

6. General Map of Santa Ana No. 3 Project [map of all three power house systems], Exhibit J, Jan. 25, 1956 (Sheet No. 1; for filing with Federal Power Commission). On file, No. 535041. Southern California Edison, Rosemead.

Santa Ana Power House No. 1

1. Tail Race at Santa Ana No. 1 Power Station, Dec. 5, 1910. Drawn by J.A.R. On file, No. 5282 (former number 488-28), Southern California Edison, Rosemead.

2. 82-Inch Pelton Nozzle on G.E. Gen. Base, Santa Ana River No. 1, June 19, 1909. On file, No. 5309 (former number 1586-9), Southern California Edison, Rosemead.

3. Water Wheel for Air Compressor and Shop, SAR No. 1, No. 15, 1897. On file, No. 5316 (former number 1603-23), Southern California Edison, Rosemead.

4. Plan No. 2 of Details and Vertical and Horizontal Curves for 2nd Force Main of Santa Ana Canyon Power Plant No. 1. Edison Electric Co., May 18, 1903, F.C. Finkle. Chief Hydraulic Engineer. On file, No. 5551 (former number 3717-70), Southern California Edison, Rosemead.

5. Amended Plan, Hor. and Vertical Curves, Nos. 8, 9, 10, 1, 2, 3 and 4, for 2nd Force Main of Santa Ana River Power Plant No. 1 of Edison Electric Co., Approved August 10, 1905, F.C. Finkle, Chief Hydraulic Engineer. On file, No. 5552 (former number 3718-70), Southern California Edison, Rosemead.

6. Gate Lift, Santa Ana River No. 1 and Mill Creek No. 3, May 3, 1910. Drawn by F.G.M. On file, No. 3701 or 5591 (former number 3701-26), Southern California Edison, Rosemead.

7. Plan No. 1 of Details and Vertical and Horizontal Curves for 2nd Force Main of Santa Ana Canyon Power Plant No. 1, Edison Electric Co., Approved May 18, 1903, F.C. Finkle, Chief Hydraulic Engineer. On file, No. 5602 (former number 3761-70), Southern California Edison, Rosemead.

8. Dam at Settling Basin, Santa Ana River No. 1, Sept. 9, 1912. On file. No. 5787 (former number 5055-30). Southern California Edison, Rosemead.

9. Record Plan of Dam at Settling Basin, Santa Ana River No. 1. May 12. 1914. Drawn by F.G.M. On file, No. 5848 (former number 6931-21), Southern California Edison. Rosemead.

10. Map Showing Parts of Tunnels 18 and 19, Santa Ana River P.P. No. 1, Surveys Over Divide and Contour Line on Keller Creek Side. With Position of Slide, (no date). On file, No. 53995 (former number 143-74), Southern California Edison, Rosemead.

11. Flume Replacement, 1925-26, Flume No. 1 and Intake, Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510220, Southern California Edison, Rosemead.

12. Flume Replacement, 1925-26, Flume No. 2, Santa Ana River No. 1, Jan. 8, 1926. On file. No. 510221, Southern California Edison, Rosemead.

13. Flume Replacement, 1925-26. Flume Nos. 4-5, Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510222, Southern California Edison, Rosemead.

14. Flume Replacement, 1925-26, Flume Nos. 4-5, Santa Ana River No. 1, Jan. 8. 1926. On file. No. 510223. Southern California Edison, Rosemead.

15. Flume Replacement. 1925-26. Flume Nos. 4-5, Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510224. Southern California

Edison. Rosemead.

16. Flume Replacement, 1925-26. Flume No. 6. Santa Ana River No. 1. Jan. 8. 1926. On file, No. 510225, Southern California Edison, Rosemead.

17. Flume Replacement, 1925-26. Flume No. 7. Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510226, Southern California Edison, Rosemead.

18. Flume Replacement, 1925-26, Flume No. 10. Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510228, Southern California Edison. Rosemead.

19. Flume Replacement, 1925-26. Flume No. 11. Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510229, Southern California Edison, Rosemead.

20. Flume Replacement, 1925-26, Flume No. 12. Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510230, Southern California Edison, Rosemead.

21. Flume Replacement. 1925-26, Flume No. 13, Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510231, Southern California Edison, Rosemead.

22. Flume Replacement, 1925-26. Flume No. 14, Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510232, Southern California Edison, Rosemead.

23. Flume Replacement, 1925-26, Flume No. 15. Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510233, Southern California Edison, Rosemead.

24. Flume Replacement. 1925-26, Flume No. 16, Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510234, Southern California Edison, Rosemead.

25. Flume Replacement. 1925-26. Flume No. 17. Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510235, Southern California Edison. Rosemead.

26. Flume Replacement, 1925-26. Typical Details of Flume. Santa Ana River No. 1, Jan. 8. 1926. On file, No. 510247, Southern California Edison. Rosemead.

27. Flume Replacement, 1925-26. Curves and Transitions. Santa Ana River No. 1, Jan. 8, 1926. On file, No. 510248. Southern California Edison, Rosemead.

28. Flume Replacement, 1925-26, Diversion Dam for S.A.R. 1, Santa Ana River No. 1, Jan. 8, 1926. On file. No. 510252, Southern California Edison, Rosemead.

29. Alignment of Conduit and Cross-Section and Lining of Tunnels, Santa Ana No. 1, June 17, 1926 (Sheet 1 of 4). Survey by L.M. Shappell; Plotted by J.C. DeWitt. On file No. 511811, Southern California Edison, Rosemead.

30. Alignment of Conduit and Cross-Section and Lining of Tunnels, Santa Ana No. 1, June 1926 (Sheet 2 of 4). Survey by L.M. Shappell; Plotted by J.C. DeWitt. On file, No. 511812, Southern California Edison, Rosemead.

31. Alignment of Conduit and Cross-Section and Lining of Tunnels, Santa Ana No. 1, June 1926 (Sheet 3 of 4). Survey by L.M. Shappell and G.R. O'Melveny; Plotted by J.C. DeWitt. On file, No. 511813, Southern California Edison, Rosemead.

32. Alignment of Conduit and Cross-Section and Lining of Tunnels, Santa Ana No. 1, June 1926 (Sheet 4 of 4). Survey by G.R. O'Melveny; Plotted by J.C. DeWitt. On file, No. 511814, Southern California Edison, Rosemead.

33. Pipe and Bridge Replacing, Flume 3, 1927, Santa Ana No. 1, Aug. 1927. On file, No. 521552, Southern California Edison, Rosemead.

34. Bear Creek and Santa Ana River Diversion Dams and Concrete Conduit No. 1, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523191 (Sheet No. 1; for filing with Federal Power Commission), Southern California Edison, Rosemead.

35. Rock Drop and Fish Wheel, Conduit No. 1 Spillway, Flume No. 17, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523192 (Sheet No. 2; for filing with Federal Power Commission), Southern California Edison, Rosemead.

36. Settling Basin Between Tunnels 3-4, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523193 (Sheet No. 3; for filing with Federal Power Commission), Southern California Edison, Rosemead.

37. Details of Steel Flume, Typical Curves and Transitions, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523195 (Sheet No. 5; for filing with Federal Power Commission), Southern California Edison, Rosemead.

38. Details of Steel Flume, Typical Bents and Trusses, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523196 (Sheet No. 6; for filing with Federal Power Commission), Southern California Edison, Rosemead.

39. Penstocks, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523197 (Sheet No. 7; for filing with Federal Power Commission), Southern California Edison, Rosemead.

40. Plan of Power House, Exhibit L, Santa Ana River No. 1

Project, Apr. 30, 1945. On file, No. 523198 (Sheet No. 8; for filing with Federal Power Commission), Southern California Edison, Rosemead.

41. Cross Section of Power House, Exhibit L, Santa Ana River No. 1 Project, Apr. 30, 1945. On file, No. 523199 (Sheet No. 9; for filing with Federal Power Commission), Southern California Edison, Rosemead.

42. Intake and Power House Areas, Santa Ana No. 1; Detail Map of Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523690 (Sheet No. 5; for filing with Federal Power Commission), Southern California Edison, Rosemead.

43. Profile of Santa Ana No. 1 Conduit Line; Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523692 (Sheet No. 7; for filing with Federal Power Commission), Southern California Edison, Rosemead.

44. Plot Plan, Santa Ana No. 1 Hydro Plant, Oct. 8, 1958. On file, No. 554238-0, Southern California Edison, Rosemead.

45. Building Floor Plan, Santa Ana No. 1 Hydro Plant, Oct. 8, 1958. On file, No. 554239-0, Southern California Edison, Rosemead.

46. Miscl. Steel Details, Santa Ana No. 1 Hydro Plant, Oct. 8, 1958. On file, No. 554240-0, Southern California Edison, Rosemead.

47. Elementary Wiring Diagram, 33 KV and 2.4 KV AC Control, Santa Ana No. 1 Hydro-Plant, Oct. 27, 1958. On file, No. 554242-0, Southern California Edison, Rosemead.

48. Elementary Wiring Diagram, 33 KV and 2.4 KV DC Control, Santa Ana No. 1 Hydro-Plant, Oct. 27, 1958; Revisions, May 6, 1965. On file, No. 554243-1, Southern California Edison, Rosemead.

49. Elect. Equip. Plan, Powerhouse, Santa Ana No. 1 Hydro Plant, Jan. 29, 1958. On file, No. 554256-0, Southern California Edison, Rosemead.

50. Conduit Plan, Powerhouse, Santa Ana No. 1 Hydro-Plant, Oct. 6, 1958; Revisions, Oct. 27, 1958, and June 21, 1965. On file, No. 554257-2, Southern California Edison, Rosemead.

51. Repair of Tunnel No. 8 and Flume No. 8, Santa Ana No. 1, Aug. 22, 1969; Revisions, Sept. 24, 1969, Jan. 6 and Apr. 13, 1970. On file, No. 5101802-3, Southern California Edison, Rosemead.

52. Details for Repair of Tunnel No. 8 and Flume No. 8, Santa Ana No. 1, Sept. 22, 1969; Revisions, Jan. 6, and Apr. 6, 1970.

On file, No. 5101816-2, Southern California Edison, Rosemead.

53. Conduit Between Tunnel No. 8 and No. 9 and Details. Exhibit L, Santa Ana River No. 1 Project (Sheet No. 4), July 30, 1970. On file, No. 5104256, Southern California Edison, Rosemead.

54. Annunciator and Alarms, Schematic Diagram. Santa Ana River No. 1, Aug. 15, 1978. On file, No. 5134209-0, Southern California Edison, Rosemead.

55. Bear Creek and Santa Ana River Diversion Dams and Concrete Conduit No. 1, Project 1933, Exhibit F, Santa Ana Powerhouse No. 1, (no date; FERC No. 1933-41). On file, No. 5206851, Southern California Edison, Rosemead.

56. Rock Drop, Fish Wheel, Conduit No. 1 Spillway and Flume No. 17, Project 1933, Exhibit F, Santa Ana Powerhouse No. 1, (no date; FERC No. 1933-42). On file, No. 5206852, Southern California Edison, Rosemead.

57. Settling Basin Between Tunnels 3 and 4, Project 1933, Exhibit F, Santa Ana Powerhouse No. 1, (no date; FERC No. 1933-43). On file, No. 5206853, Southern California Edison, Rosemead.

58. Penstocks, Project 1933, Exhibit F, Santa Ana Powerhouse No. 1, (no date; FERC No. 1933-44). On file, No. 5206854, Southern California Edison, Rosemead.

59. Plan of Powerhouse, Project 1933, Exhibit F, Santa Ana Powerhouse No. 1, (no date; FERC No. 1933-45). On file, No. 5206855, Southern California Edison, Rosemead.

60. Cross Section of Powerhouse, Project 1933, Exhibit F, Santa Ana Powerhouse No. 1, (no date: FERC No. 1933-46). On file, No. 5206856, Southern California Edison, Rosemead.

Santa Ana Power House No. 2

1. Power House Santa Ana No. 2 (plan and views), Nov. 14, 1910. Drawn by J.A.R. On file, No. 5277 (former number 459-28). Southern California Edison, Rosemead.

2. External Elevations, Power House Santa Ana River No. 2. Edison Electric Co., Nov. 3, 1904. On file, No. 5392 (former number 2445-23), Southern California Edison, Rosemead.

3. Foundations - Tail Race, Etc., Power House Santa Ana River No. 2, Edison Electric Co., Nov. 3, 1904. On file, No. 5393 (former number 2446-23), Southern California Edison, Rosemead.

4. Longitudinal Section - Power House S.A.R. No. 2, Edison

Electric Co.. Nov. 3, 1904. On file, No. 5394 (former number 2447-23), Southern California Edison. Rosemead.

5. Plan of Conduit and Station Lighting. S.A.R. No. 2. Edison Electric Co., Nov. 30, 1904. Drawn by LJ. On file. No. 5398 (former number 2460-23). Southern California Edison. Rosemead.

6. Details for Curves Etc. for Keller Creek Pipe Line. Santa Ana River Power Plant No. 2 of the Edison Electric Co., Approved Jan. 12, 1904, F.C. Finkle, Chief Hydraulic Engineer. On file, No. 5601 (former number 3760-70), Southern California Edison, Rosemead.

7. Amended Drawings of Sand Box at End of Siphon No. 1. Santa Ana River Power Plant No. 2, Edison Electric Co.. Approved May 5, 1904. F.C. Finkle, Chief Hydraulic Engineer. On file. No. 5634 (former number 3873-71). Southern California Edison. Rosemead.

8. Details for Curves Etc., Alder Creek Pipe Line. Santa Ana River Power Plant No. 2 of the Edison Electric Co., Approved Jan. 12. 1904. F.C. Finkle, Chief Hydraulic Engineer. On file. No. 5637 (former number 3877-71), Southern California Edison, Rosemead.

9. Curves and Syphon No. 1. Santa Ana River Power Plant No. 2 of the Edison Electric Co., Approved Jan. 12. 1904, F.C. Finkle, Chief Hydraulic Engineer. On file. No. 5638 (former number 3878-71). Southern California Edison, Rosemead.

10. Details for Curves Etc., Dirt Canon Double Syphon. Santa Ana River Power Plant No. 2 of the Edison Electric Co., Approved Feb. 2, 1904, F.C. Finkle, Chief Hydraulic Engineer. On file, No. 5639 (former number 3879-71), Southern California Edison, Rosemead.

11. Standpipe Blow Off and Manholes, Santa Ana River Power Plant No. 2, of the Edison Electric Co.. Approved Feb. 2, 1904, F.C. Finkle, Chief Hydraulic Engineer. On file. No. 5647 (former number 3891-72), Southern California Edison, Rosemead.

12. 800 H.P. Water Wheel Unit (Left Hand) Direct Connected to a 500 K.W. G.E. Co. Generator, Speed 176 R.P.M., Head of Water 305 Ft Eff., for Santa Ana River No. 2 Plant. Abner Doble Co., Engineers, San Francisco, Aug. 29, 1904. Traced from Doble Blue Print, Sept. 9, 1911. On file. No. 5698 (former number 4400-30), Southern California Edison, Rosemead.

13. Foundation for 2 800-HP Waterwheel Units, Speed 176 RPM, and 2 40-HP Exciter Units, Speed 750 R.P.M., Eff. Head of Water=305 Ft. Abner Doble Co., Engineers, San Francisco. Traced from Doble Blue Print, Sept. 12, 1911. On file. No. 5699 (former number 4401-30), Southern California Edison, Rosemead.

14. Blow Off Valves for Syphons. Dirt Canyon, Alder and Keller

Creeks and Santa Ana No. 2, Edison Electric Co., Approved Feb. 2, 1904, F.C. Finkle, Chief Hydraulic Engineer. On file, No. 5642 (former number 3884-71). Southern California Edison, Rosemead.

15. Enlarged Nozzle Diameter and New Needle Tip, Santa Ana River No. 2, May 12, 1920. On file, No. 53053 (former number 20938-409), Southern California Edison, Rosemead.

16. Profile of Siphon No. 1, Santa Ana River Power Plant No. 2, Edison Electric Co., Approved Jan. 12, 1904, F.C. Finkle, Chief Hydraulic Engineer. On file, No. 53940 (former number 352-64), Southern California Edison, Rosemead.

17. Map of Santa Ana River Power Plant No. 2 of the Edison Electric Co. Through Unsurveyed Land in the San Bernardino Forest Reserve, Approved May 26, 1904, F.C. Finkle, Chief Hydraulic Engineer. On file, No. 53988 (former number 50-74), Southern California Edison, Rosemead.

18. 8 1/8-Inch Special Nozzle Tip, Santa Ana River No. 2, Jan. 3, 1925. On file, No. 56146, Southern California Edison, Rosemead.

19. Plan, Elevations, and Sections, Transformer Rack, Santa Ana River No. 2, Nov. 8, 1927. On file, No. 515297, Southern California Edison, Rosemead.

20. Assembly and Details of Steel Dead End Rack, Santa Ana River No. 2, Nov. 5, 1927. On file, No. 515324, Southern California Edison, Rosemead.

21. Foundations for Oil Switch and Transformers, Etc., Santa Ana River No. 2, Nov. 5, 1927. On file, No. 515394, Southern California Edison, Rosemead.

22. 8 3/8-Inch Special Nozzle Tip and Needle,, Unit No. 1, Santa Ana No. 2, Mar. 17, 1928. On file, No. 515952, Southern California Edison, Rosemead.

23. Special Nozzle Tip and Needle Point for Hydraulic Turbine, Santa Ana R. No. 2, May 21, 1940. On file, No. 522392-0, Southern California Edison, Rosemead.

24. Intakes, S.A.R. 2 and Keller Creek, Exhibit L, Santa Ana River No. 2 Project, Apr. 30, 1945. On file, No. 523639 (Sheet No. 10: for filing with Federal Power Commission), Southern California Edison, Rosemead.

25. Siphons No. 1 and Dirt Canyon, Exhibit L, Santa Ana River No. 2 Project, Apr. 30, 1945. On file, No. 523640 (Sheet No. 11; for filing with Federal Power Commission), Southern California Edison, Rosemead.

26. Alder Creek Diversion, Exhibit L, Santa Ana River No. 2

Project, Apr. 30, 1945. On file, No. 523641 (Sheet No. 12; for filing with Federal Power Commission), Southern California Edison, Rosemead.

27. Forebay and Penstock, Exhibit L, Santa Ana River No. 2 Project, Apr. 30, 1945. On file, No. 523642 (Sheet No. 13; for filing with Federal Power Commission), Southern California Edison, Rosemead.

28. Floor Plan of Power House, Exhibit L, Santa Ana River No. 2 Project, Apr. 30, 1945. On file, No. 523643 (Sheet No. 14; for filing with Federal Power Commission), Southern California Edison, Rosemead.

29. Sections of Power House, Exhibit L, Santa Ana River No. 2 Project, Apr. 30, 1945. On file, No. 523644 (Sheet No. 15; for filing with Federal Power Commission), Southern California Edison, Rosemead.

30. Power House Area, Santa Ana No. 2: Detail Map of Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523691 (Sheet No. 6; for filing with Federal Power Commission), Southern California Edison, Rosemead.

31. Profile of Santa Ana No. 2 Conduit Line: Santa Ana No. 1 and No. 2 Hydroelectric Project, Exhibit K, Apr. 30, 1945. On file, No. 523693 (Sheet No. 8; for filing with Federal Power Commission), Southern California Edison, Rosemead.

32. Steel for Indoor Switchrack, Erection Diagram and Shop Details, Santa Ana River No. 2, Dec. 3, 1951. On file, No. 531869-0, Southern California Edison, Rosemead.

33. Schematic Diagram Annunciator and Semi-Automatic Control, Santa Ana River No. 2, Oct. 27, 1977. On file, No. 534983-1, Southern California Edison, Rosemead.

34. Switchboard Elevations, Santa Ana River No. 2, Dec. 14, 1951; Revisions, Mar. 20 and Sept. 19, 1952. On file, No. 534984-2, Southern California Edison, Rosemead.

35. Partial Floor Plan Showing Indoor 750 Volt Switchrack and Misc. Equipment, Santa Ana River No. 2, Dec. 11, 1951; Revisions, Dec. 14, 1951. On file, No. 534985-1, Southern California Edison, Rosemead.

36. Indoor Switchrack, Elevation and Sections, Santa Ana River No. 2, Dec. 11, 1951; Revisions, Dec. 14, 1951, and Mar. 20, 1952. On file, No. 534986-2, Southern California Edison, Rosemead.

37. Dirt Canyon Siphon Replacement, Santa Ana No. 2, (no date). On file, No. 5105085-1, Southern California Edison, Rosemead.

38. Siphon No. 1, Exhibit L, Santa Ana River No. 2 Project. May 22, 1973 (Sheet No. 11). On file, No. 5110869, Southern California Edison, Rosemead.

39. Dirt Canyon Siphon. Exhibit L, Santa Ana River No. 2 Project. May 22, 1973 (Sheet No. 16). On file. No. 5110870, Southern California Edison, Rosemead.

40. Intakes, S.A.R. 2 and Keller Creek. Exhibit L, Santa Ana River No. 2 Project, May 22, 1973 (Sheet No. 10). On file, No. 5114220, Southern California Edison, Rosemead.

41. Intakes. S.A.R. No. 2 and Keller Creek, Project 1933, Exhibit F, Santa Ana Powerhouse No. 2. (no date: FERC No. 1933-47). On file, No. 5206857, Southern California Edison. Rosemead.

42. Alder Creek Diversion, Project 1933, Exhibit F. Santa Ana Powerhouse No. 2, (no date; FERC No. 1933-48). On file, No. 5206858, Southern California Edison, Rosemead.

43. Floor Plan of Powerhouse, Project 1933, Exhibit F, Santa Ana Powerhouse No. 2, (no date: FERC No. 1933-49). On file. No. 5206859, Southern California Edison, Rosemead.

Santa Ana Power House No. 3

1. Building Plans for Mentone Power House, Pacific Light and Power Co., Oct. 7. 1903. R.S. Masson, Consulting Electrical Engineer, San Francisco & Los Angeles. On file, No. 52306 (former number 14877-327), Southern California Edison, Rosemead.

2. Duct Lines and Holes to be Left in Transformer Room and Gallery, Mentone, Mar. 13, 1904. R.S. Masson, Consulting Electrical Engineer, San Francisco & Los Angeles. On file. No. 52319 (former number 14898-327), Southern California Edison, Rosemead.

3. A.C. Panel for Mentone Power House, P.L. & P. Co., Los Angeles. Retraced from Masson's drawing No. C-275, Jan. 20, 1909. On file, No. 52880 (former number 17313-327). Southern California Edison, Rosemead.

4. 30-K.V. Switch Rack, Erection Diagram and Details, Apr. 17. 1925. On file, No. 56362, Southern California Edison, Rosemead.

5. Foundation and Details for 30-K.V. Switch Rack, Santa Ana River No. 3 Power House, Apr. 17, 1925. On file, No. 56380-2, Southern California Edison, Rosemead.

6. Arrangement of Operating Mechanism Adapting P.E. Baum Type 35 K.V. Pole Top Disc. Switch to 30 K.V. Steel Switch Rack. Santa

Ana River No. 3, Apr. 17, 1925. On file, No. 56390, Southern California Edison, Rosemead.

7. Flume Replacement, 1925-26. Flume Nos. 1-2. Santa Ana River No. 3, Feb. 23, 1926 (Sheet 1 of 9 Sheets). On file. No. 510254, Southern California Edison, Rosemead.

8. Flume Replacement, 1925-26. Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 2 of 9 Sheets). On file. No. 510255. Southern California Edison, Rosemead.

9. Flume Replacement, 1925-26. Flume Nos. 1-2. Santa Ana River No. 3, Feb. 23, 1926 (Sheet 3 of 9 Sheets). On file, No. 510256. Southern California Edison, Rosemead.

10. Flume Replacement, 1925-26, Flume Nos. 1-2. Santa Ana River No. 3, Feb. 23, 1926 (Sheet 4 of 9 Sheets). On file. No. 510257. Southern California Edison, Rosemead.

11. Flume Replacement, 1925-26, Flume Nos. 1-2. Santa Ana River No. 3, Feb. 23, 1926 (Sheet 5 of 9 Sheets). On file. No. 510258, Southern California Edison, Rosemead.

12. Flume Replacement, 1925-26. Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 6 of 9 Sheets). On file, No. 510259. Southern California Edison, Rosemead.

13. Flume Replacement, 1925-26, Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926; Revisions. Mar. 10, 1926 and Apr. 6, 1926 (Sheet 7 of 9 Sheets). On file, No. 510260. Southern California Edison, Rosemead.

14. Flume Replacement, 1925-26, Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 8 of 9 Sheets). On file, No. 510261, Southern California Edison, Rosemead.

15. Flume Replacement, 1925-26, Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 9 of 9 Sheets). On file. No. 510262, Southern California Edison, Rosemead.

16. Flume Replacement, 1925-26, Flume No. 3, Santa Ana River No. 3, Feb. 10, 1926; Revisions, Mar. 20 and Apr. 6, 1926 (Sheet 1 of 7 Sheets). On file, No. 510263, Southern California Edison, Rosemead.

17. Flume Replacement, 1925-26. Flume No. 3. Santa Ana River No. 3, Feb. 10, 1926; Revisions, Mar. 20 and Apr. 6. 1926 (Sheet 2 of 7 Sheets). On file, No. 510264, Southern California Edison, Rosemead.

18. Flume Replacement, 1925-26. Flume No. 3. Santa Ana River No. 3, Feb. 10, 1926 (Sheet 3 of 7 Sheets). On file, No. 510265. Southern California Edison, Rosemead.

Ana River No. 3, Apr. 17, 1925. On file. No. 56390. Southern California Edison, Rosemead.

7. Flume Replacement, 1925-26. Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 1 of 9 Sheets). On file, No. 510254, Southern California Edison, Rosemead.

8. Flume Replacement, 1925-26. Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 2 of 9 Sheets). On file. No. 510255. Southern California Edison, Rosemead.

9. Flume Replacement, 1925-26, Flume Nos. 1-2. Santa Ana River No. 3, Feb. 23, 1926 (Sheet 3 of 9 Sheets). On file. No. 510256, Southern California Edison, Rosemead.

10. Flume Replacement, 1925-26, Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 4 of 9 Sheets). On file, No. 510257, Southern California Edison, Rosemead.

11. Flume Replacement, 1925-26, Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 5 of 9 Sheets). On file, No. 510258, Southern California Edison, Rosemead.

12. Flume Replacement, 1925-26, Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 6 of 9 Sheets). On file. No. 510259, Southern California Edison, Rosemead.

13. Flume Replacement, 1925-26, Flume Nos. 1-2, Santa Ana River No. 3. Feb. 23, 1926; Revisions, Mar. 10, 1926 and Apr. 6, 1926 (Sheet 7 of 9 Sheets). On file, No. 510260, Southern California Edison, Rosemead.

14. Flume Replacement, 1925-26, Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 8 of 9 Sheets). On file, No. 510261, Southern California Edison, Rosemead.

15. Flume Replacement. 1925-26, Flume Nos. 1-2, Santa Ana River No. 3, Feb. 23, 1926 (Sheet 9 of 9 Sheets). On file, No. 510262, Southern California Edison, Rosemead.

16. Flume Replacement, 1925-26, Flume No. 3. Santa Ana River No. 3, Feb. 10, 1926; Revisions. Mar. 20 and Apr. 6, 1926 (Sheet 1 of 7 Sheets). On file, No. 510263, Southern California Edison, Rosemead.

17. Flume Replacement, 1925-26. Flume No. 3. Santa Ana River No. 3, Feb. 10, 1926; Revisions, Mar. 20 and Apr. 6. 1926 (Sheet 2 of 7 Sheets). On file, No. 510264. Southern California Edison. Rosemead.

18. Flume Replacement, 1925-26. Flume No. 3, Santa Ana River No. 3, Feb. 10, 1926 (Sheet 3 of 7 Sheets). On file, No. 510265, Southern California Edison, Rosemead.

19. Flume Replacement, 1925-26, Flume No. 3, Santa Ana River No. 3, Feb. 10, 1926 (Sheet 4 of 7 Sheets). On file. No. 510266. Southern California Edison, Rosemead.

20. Flume Replacement, 1925-26, Flume No. 3, Santa Ana River No. 3, Feb. 10, 1926 (Sheet 5 of 7 Sheets). On file. No. 510267. Southern California Edison, Rosemead.

21. Flume Replacement, 1925-26, Flume No. 3. Santa Ana River No. 3, Feb. 10, 1926 (Sheet 6 of 7 Sheets). On file, No. 510268. Southern California Edison, Rosemead.

22. Flume Replacement, 1925-26, Flume No. 3, Santa Ana River No. 3, Feb. 10, 1926 (Sheet 7 of 7 Sheets). On file, No. 510269, Southern California Edison, Rosemead.

23. Flume Replacement, 1925-26, General Details of Trestle, Flume 1-2, Santa Ana River No. 3, Feb. 5, 1926 (Sheet 1 of 3 Sheets). On file. No. 510510, Southern California Edison, Rosemead.

24. Flume Replacement, 1925-26, General Details of Trestle, Flume 1-2, Santa Ana River No. 3, Feb. 5, 1926 (Sheet 2 of 3 Sheets). On file, No. 510511, Southern California Edison, Rosemead.

25. Flume Replacement, 1925-26, General Details of Trestle, Flume 1-2, Santa Ana River No. 3, Feb. 5, 1926 (Sheet 3 of 3 Sheets). On file, No. 510512, Southern California Edison, Rosemead.

26. Flume Replacement, 1925-26, Concrete Flume for Tailrace, P.H. 2, Santa Ana River No. 3, Feb. 5, 1926. On file, No. 510513, Southern California Edison, Rosemead.

27. Flume Replacement, 1925-26, Detail of Transitions, Santa Ana River No. 3, Feb. 5, 1926. On file, No. 510527, Southern California Edison, Rosemead.

28. Flume Replacement, 1925-26, Typical Details, Santa Ana River No. 3, Feb. 10, 1926. On file, No. 510528, Southern California Edison, Rosemead.

29. Alignment of Conduit and Cross-Section and Lining of Tunnels, Santa Ana No. 3, June 1926 (Sheet 1 of 3). Survey by O'Melveny and Marchand: Plotted by J.C. DeWitt. On file, No. 511815, Southern California Edison, Rosemead.

30. Alignment of Conduit and Cross-Section and Lining of Tunnels, Santa Ana No. 3, June 1926 (Sheet 2 of 3). Survey by Marchand, Wurdeman, and Dickens: Plotted by J.C. DeWitt. On file, No. 511816, Southern California Edison, Rosemead.

31. Alignment of Conduit and Cross-Section and Lining of

Tunnels, Santa Ana No. 3. June 1926 (Sheet 3 of 3). Survey by Dickens and Densmore; Plotted by J.C. DeWitt. On file. No. 511817, Southern California Edison, Rosemead.

32. Alignment of Conduit and Tunnels, Index Map, Santa Ana No. 3, June 1926. Survey by Marchand Wurdeman, Dickens, Densmore: Plotted by D.L. Brown. On file, No. 511819, Southern California Edison, Rosemead.

33. Assembly Showing Location of Baffles for Tailrace, Santa Ana No. 3, Dec. 28, 1928. On file, No. 517909, Southern California Edison, Rosemead.

34. 54-Inch I.D. Pipe on Temporary Supports, Replacing Tail Race Flume Destroyed, 1938, Santa Ana No. 3, May 5, 1938. On file. No. 521871-0, Southern California Edison, Rosemead.

35. Repairs to Tail Race Using 54-Inch Pipe from Redonda Steam Plant, Santa Ana No. 3, July 5, 1938. On file, No. 521906-0, Southern California Edison, Rosemead.

36. Addition to Tail Race, Concrete Details, Santa Ana No. 3, July 12, 1938. On file, No. 521908, Southern California Edison, Rosemead.

37. Plan and Sections Showing Installation of Hydraulic Turbine Unit from Kaweah No. 2 Replacing Existing Unit, Santa Ana River No. 3, June 21, 1945. On file, No. 523126-1, Southern California Edison, Rosemead.

38. Detail of Pipe and Changes at Forebay for Replacing Approx. 180 Ft. of Upper End of Existing Penstock, Santa Ana River No. 3, Oct. 5, 1942; Revisions, Nov. 19, 1942. On file, No. 523134-1, Southern California Edison, Rosemead.

39. Electrical Equipment, Plan for Power House, Santa Ana River P.H. No. 3, June 23, 1943; Revisions, Mar. 14, 1945 and May 17, 1954. On file, No. 523219-2, Southern California Edison, Rosemead.

40. Installation of Hydraulic Turbine From Kaweah No. 2, Replacing Existing Unit Foundations, Santa Ana River No. 3, (no date). On file, No. 523227-0, Southern California Edison, Rosemead.

41. Installation of Hydraulic Turbine From Kaweah No. 2, Replacing Existing Unit Spillway Pipe, Santa Ana River No. 3, June 1, 1943. On file, No. 523228-1, Southern California Edison, Rosemead.

42. Crane Runway for 5-Ton Push Type Crane, Santa Ana River No. 3, Sept. 4, 1945. On file, No. 523856-2, Southern California Edison, Rosemead.

43. Warehouse and Garage Building, Foundation Plan and Struct. Details, Santa Ana Hydro Plant No. 3, July 27, 1950. On file. No. 533006-0, Southern California Edison. Rosemead.

44. Warehouse and Garage Building, Roof Framing Plan and Steel Details, Santa Ana Hydro Plant No. 3. July 27, 1950. On file. No. 533007-0, Southern California Edison, Rosemead.

45. Warehouse and Garage Building, Electrical Plan and Details. Santa Ana Hydro Plant No. 3, July 27, 1950. On file, No. 533008-0, Southern California Edison, Rosemead.

46. Detail Map of Santa Ana No. 3 Project, Exhibit K. Jan. 25, 1956 (Sheet 2; for filing with Federal Power Commission). On file, No. 535042, Southern California Edison, Rosemead.

47. Typical Details of Lennon Flume. Santa Ana No. 3. Exhibit L, Jan. 25, 1956 (Sheet 4; for filing with Federal Power Commission). On file, No. 541722, Southern California Edison, Rosemead.

48. High Lennon Flume, Santa Ana No. 3, Exhibit L. Jan. 25, 1956 (Sheet 3; for filing with Federal Power Commission). On file, No. 541723, Southern California Edison. Rosemead.

49. Spillways and Rock-Drop, Santa Ana No. 3, Exhibit L. Jan. 25, 1956 (Sheet 5; for filing with Federal Power Commission). On file, No. 541724, Southern California Edison, Rosemead.

50. Tailrace and Forebay, Santa Ana No. 3, Exhibit L, Jan. 25, 1956 (Sheet 6; for filing with Federal Power Commission). On file, No. 541725, Southern California Edison, Rosemead.

51. Plan and Profiles of Penstock and Spillway Pipe, Santa Ana No. 3, Exhibit L, Jan. 25, 1956 (Sheet 7; for filing with Federal Power Commission). On file. No. 541726, Southern California Edison, Rosemead.

52. Sandbox Between Tunnels 1-2, Santa Ana No. 3. Exhibit L, Jan. 25, 1956 (Sheet 2; for filing with Federal Power Commission). On file, No. 541727, Southern California Edison, Rosemead.

53. Intake Flume and Tunnel Sections. Santa Ana No. 3. Exhibit L, Jan. 25, 1956 (Sheet 1; for filing with Federal Power Commission). On file. No. 541728. Southern California Edison, Rosemead.

54. Plans and Sections of Powerhouse. Santa Ana No. 3. Exhibit L, Jan. 25, 1956 (Sheet 8; for filing with Federal Power Commission). On file. No. 541729. Southern California Edison. Rosemead.

55. SAR 3 Flume Truss, Santa Ana River, Jan. 19, 1970. On file,

No. 5101154-0, Southern California Edison, Rosemead.

56. 41 Feet Flume Truss. Steel Details, Sheet 1. Santa Ana River No. 3, Jan. 19, 1970. On file. No. 5101514-0, Southern California Edison, Rosemead.

57. 41 Feet Flume Truss, Steel Details, Sheet 2. Santa Ana River No. 3, Jan. 19, 1970. On file, No. 5101515-0, Southern California Edison, Rosemead.

58. Project 2198, Exhibit G, Santa Ana Powerhouse No. 3 [general map], (no date; FERC No. 2198-11). On file, No. 5187987, Southern California Edison, Rosemead.

59. Intake Flume and Tunnel Sections, Project 2198, Exhibit F, Santa Ana Powerhouse No. 3, (no date; FERC No. 2198-12). On file, No. 5187988, Southern California Edison, Rosemead.

60. Sandbox Between Tunnels 1 and 2, Project 2198, Exhibit F, Santa Ana Powerhouse No. 3, (no date; FERC No. 2198-13). On file, No. 5187989, Southern California Edison, Rosemead.

61. Spillway and Rock-Drop, Project 2198, Exhibit F, Santa Ana Powerhouse No. 3, (no date; FERC No. 2198-14). On file, No. 5187990, Southern California Edison, Rosemead.

62. Tailrace and Forebay, Project 2198, Exhibit F, Santa Ana Powerhouse No. 3, (no date; FERC No. 2198-15). On file, No. 5187991, Southern California Edison, Rosemead.

63. Plans and Sections of Powerhouse, Project 2198, Exhibit F, Santa Ana Powerhouse No. 3, (no date; FERC No. 2198-16). On file, No. 5187992, Southern California Edison, Rosemead.

Selection of Photographs. SAR 1-3, 27 March 1992

Number	Subject/Date (if available)
Santa Ana River Powerhouse 1	
EEC 26	SAR 1, original excavation (B.F. Pearson)
EEC 27	SAR 1, initial construction (B.F. Pearson)
EEC 28	SAR 1. initial construction (B.F. Pearson)
EEC 29	SAR 1, initial construction (B.F. Pearson)
EEC 31	SAR 1, interior under construction (B.F. Pearson)
EEC 33	SAR 1, interior under construction (B.F. Pearson)
EEC 35	SAR 1, tail races (B.F. Pearson)
EEC 43	SAR 1, machine shop equipment (B.F. Pearson)
EEC 77	SAR 1, sandbox on flume (B.F. Pearson)
EEC 88	SAR 1, exterior, c.1902
EEC 95	SAR 1. interior shot, c.1902 (B.F. Pearson)
EEC 148	SAR 1, Doble buckets on Pelton wheel (B.F. Pearson)
EEC 191	SAR 1, interior, c.1903 (B.F. Pearson)
EEC 269	SAR 1, tailraces and powerlines, c.1903
EEC 390	SAR 1, unknown operator
EEC 524	SAR 1, under construction
EEC 525	SAR 1, under construction
EEC 526	SAR 1, tramway moved for pipeline/penstock
EEC 527	SAR 1, construction of conduit
EEC 530	SAR 1, 2-way sandbox below intake
EEC 536	SAR 1, exterior view
EEC 539	SAR 1, interior with generators
EEC 540	SAR 1, interior with switchboard
EEC 541	SAR 1, interior view with tranformer section
EEC 558	SAR 1, headworks cottage
EEC 559	SAR 1, automatic cleaner (leaf rake)
EEC 560	SAR 1, O.H. Ensign's cottage
SCE 72	SAR 1, old forebay, 11/8/1910
1038	SAR 1, B.F. Pearson, general super't (glass plate)
1039	SAR 1, Chief Butterfield, operators (glass plate)
1199	SAR 1, switchboard, 6/6/1912
1910	SAR 1. sandbox, 5/20/1913
2676	SAR 1, interior, 6/4/1914
2677	SAR 1, interior, 6/4/1914
2678	SAR 1, new switchboard, 6/4/1914
2679	SAR 1, concrete stable, 6/4/1914
2685	SAR 1, Lombard governor, generator 4
2868	SAR 1, fish screen at headworks
2869	SAR 1, generator 1, c.1903(?) (glass plate)
SCE 3077	SAR 1, foundation of Flume 8 exposed, 1916
SCE 3704	SAR 1, new steel tower line (c.1916)
10319	SAR 1, exterior & lightning arresters, 11/1/1923
10320	SAR 1, general interior, 11/1/1923
10322	SAR 1, switchboard, 11/1/1923
10323	SAR 1, transformers, 11/1/1923
10325	SAR 1, exciters, 11/1/1923
11776	SAR 1, placing steel plates in Flume 10, 5/1/1926

Santa Ana River Powerhouse 2

EEC 147	SAR 2, intake below SAR 1 (B.F. Pearson)
3	SAR 2, general exterior. August 1908
1043	SAR 2, interior, 6/6/1912
1905	SAR 2, interior, 5/20/1913 (glass plate)
3505	SAR 2, Santa Ana Canal tunnel, 1/28/1916
3904	SAR 2, exterior with terracing, 7/13/1916
4320	SAR 2, general view
10326	SAR 2, exterior, 11/1/1923
10327	SAR 2, switchboard & transformers, 11/1/1923
10328	SAR 2, electrical work, 11/1/1923
10329	SAR 2, exciters, 11/1/1923
10330	SAR 2, generator and water wheel, 11/1/1923
10331	SAR 2, rheostats, 11/1/1923
10332	SAR 2, electrical wiring, 11/1/1923
15346	SAR 2, general view, 5/21/1928
15347	SAR 2, outside transformers, 5/21/1928
15348	SAR 2, switchboard, 5/21/1928
15349	SAR 2, back side of switchboard, 5/21/1928
20949	SAR 2, general view, 3/30/1938

Santa Ana River Powerhouse 3

4321	SAR 3, exterior & general area, 3/15/1918
10337	SAR 3, Doble water wheel, 11/1/1923
10340	SAR 3, exterior & transformers, 11/1/1923
10341	SAR 3, transformers, 11/1/1923
15236	SAR 3, exterior & new transmission, 2/23/1928
15237	SAR 3, generator, 2/23/1928
15238	SAR 3, electrical panels & phone booth, 2/23/1928
20682	SAR 3, exterior & penstock, 3/16/1938

General

EEC 477	SAR 33Kv line, where leaves canyon
EEC 478	SAR 33Kv line pole switch
EEC 479	SAR 33Kv line pole switch (different view)

Selection of Drawings, SAR 1-3, 27 March 1992

Number	Subject/Date (if available)
EEC 428	SAR 1, sections of tunnels (c.1903)
EEC 430	SAR 1, transformer arrangement & high tension wiring
EEC 431	SAR 1, plan & elevation of generator section (c.1903)
EEC 432	SAR 1, details of tail race (c.1903)
EEC 433	SAR 1, end section of powerhouse (c.1903)
EEC 443	Santa Ana type glass insulator, adopted as standard for 10Kv lines
EEC 446	Arrangement of insulators and cross-arms on 33Kv Santa Ana line